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Effects of Emotion and Age on Performance During a Think/No-Think Memory Task

Brendan D. Murray
Boston College

Keely A. Muscatell
University of California at Los Angeles

Elizabeth A. Kensinger
Boston College

Recent studies have demonstrated that young adults can voluntarily suppress information from memory when directed to. After learning novel word pairings to criterion, participants are shown individual words and instructed either to "think" about the associated word, or to put it out of mind entirely ("no-think"). When given a surprise cued recall test, participants typically show impaired recall for no-think words relative to think or "control" (un-manipulated) words. The present study investigated whether this controlled suppression effect persists in an aged population, and examined how the emotionality of the to-be-suppressed word affects suppression ability. Data from four experiments using the think/no-think task demonstrate that older and younger adults can suppress information when directed to (Experiment 1), and the age groups do not differ significantly in this ability. Experiments 2 through 4 demonstrate that both age groups can suppress words that are emotional (positive or negative valence) or neutral. The suppression effect also persists even if participants are tested using independent probe words that are semantically related to the target words but were not the studied cue words (Experiments 3 and 4). These data suggest that the cognitive functioning necessary to suppress information from memory is present in older adulthood, and that both emotional and neutral information can be successfully suppressed from memory.

Keywords: aging, emotion, think/no-think, memory suppression, encoding

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Forgetting is traditionally conceived of as a passive process: information that has been previously encoded degrades naturally over time (Jenkins & Dallenbach, 1924), or is subject to the effects of interference with other encoded information (Barnes & Underwood, 1959). When thought of this way, it would appear that we have little control over what information remains in memory. However, there are instances where it could be beneficial to strategically forget information: it is useful to put out of memory where you left your keys yesterday when trying to find them today, for example (Wessel & Merckelbach, 2006).

In recent decades, there has been investigation into how much control we have over our memories. A commonly used method for testing strategic forgetting is through the "directed forgetting" paradigm, in which study items (or lists of items) are cued to be either later remembered or forgotten (for a review of directed forgetting methodologies, see Basden, Basden, & Gargano, 1993). When participants are given a surprise memory test, they show significantly impaired recall for items or lists that they were instructed to forget relative to those they were instructed to remember. These studies suggest that processes can be engaged, either at encoding or at retrieval, to produce selective forgetting.

Another paradigm that demonstrates the ability to strategically forget information is the "think/no-think" paradigm, developed by Anderson and Green (2001). Think/no-think is an adaptation of the go/no-go behavioral paradigm (Cosantini & Hoving, 1973) for use on a paired-associates recall task. In a typical think/no-think task, participants study pairs of semantically unrelated words (e.g., ORDEAL + ROACH; the "learning phase"), and are then shown individual cue words from the studied lists (e.g., ORDEAL; the "experimental phase"). They are instructed either to recall and say aloud the associated target word (the "think" condition) or to put the associated target word out of mind entirely (the no-think condition). When given a surprise cued recall task, participants recall significantly fewer words from the no-think condition than from the think condition. Anderson and Green showed that this effect persisted even if participants were cued with an unstudied, but semantically related, cue word (e.g., INSECT + R . . . for the studied pair ORDEAL + ROACH).

One important difference between the think/no-think paradigm and other directed forgetting designs is that it assesses participants' ability to exert control over information that has been learned well. In most directed forgetting tasks, participants study test items on an item-by-item or a list-by-list basis, and are told (on either an

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Brendan D. Murray and Elizabeth A. Kensinger, Department of Psychology, Boston College; Keely A. Muscatell, Department of Psychology, University of California at Los Angeles.

Correspondence concerning this article should be addressed to Brendan D. Murray, Boston College, McGuinn Hall Rm. 301, 140 Commonwealth Ave, Chestnut Hill, MA 02467. E-mail: murrayds@bc.edu

item-by-item or list-by-list basis) which items to remember, and which to forget. What is not assessed in these paradigms is whether information is actually being encoded; therefore, forgetting effects could be due either to suppression (participants see a “forget” cue and suppress the memory as directed) or due to simply not encoding the material to begin with, regardless of the “remember” or forget instruction. This makes it difficult to disentangle intentional forgetting (i.e., forgetting induced by the forget cue) from incidental forgetting (i.e., noncue induced forgetting; Paz-Alonso et al., 2009). The think/no-think paradigm, on the other hand, requires participants to first learn items up to a certain criterion (typically half to two-thirds of the items) before any think/no-think manipulation is used, so that there is an objective measure of what participants have learned before the forgetting cues are shown. The ability to control the contents of memory can then be assessed only for the set of items known to have been successfully encoded. This methodology ensures that participants have indeed learned the items that they are then being asked to reinforce (think trials) or suppress (no think trials), and it isolates participants’ abilities to exert control over this successfully encoded information (Levy & Anderson, 2008).

Because paradigms like the think/no-think require participants to prevent information they have already encoded from coming to mind, success on this task likely relies on some active process or processes to stop the to-be-forgotten item from reaching consciousness (Anderson et al., 2004). One possible mechanism for success is inhibition: when participants are cued to forget or “not think” about a particular word that they have learned, they must inhibit the desire to think about, or recall, that particular word. Neuroimaging data suggest that inhibition may indeed play an important role in the think/no-think task. Anderson and colleagues (2004) had participants perform the learning and experimental phases of the think/no-think task while undergoing a functional MRI scan. Relative to think trials, no-think trials showed increased activation of bilateral dorsolateral and ventrolateral prefrontal cortex, regions implicated in cognitive control and inhibition, as well as reduced activity bilaterally in the hippocampus. The extensive prefrontal involvement on no-think suppression trials, coupled with the reduced hippocampal activity, supports the idea that memory suppression is an active, controlled process that may require inhibition of a prepotent response (in this case, inhibiting recall of the suppressed word).

Depue, Curran, and Banich (2007) also demonstrated that frontal regions act to down-regulate medial temporal lobe regions during memory suppression. Again using functional MRI, they reported regions of middle and inferior frontal gyrus showing greater activity during no-think than think trials, and this activity accompanied down-regulation of the hippocampus. Taken together, the results of Depue and colleagues and Anderson and colleagues (2004) provide strong evidence that the ability to use these frontal regions is critical to success on the think/no-think task and their data support the suggestion that cognitive control is essential to such performance.

These findings raise the question of how performance on the think/no-think task might be affected by advancing age. Aging is typically characterized by volumetric loss of gray matter in the brain, as well as an overall decrease in cerebral blood flow (Grieve et al., 2005). This loss is typically accelerated, relative to global gray matter loss, in the frontal cortices and temporal lobes (Albert & Kaplin, 1980; Daigneault, Braun, & Whitaker, 1992; Raz et al., 1997; Raz et al., 1993a, 1993b; see Kemper, 1994, for a review). Behaviorally, older adults tend to perform poorly, relative to younger adults, on tasks that require controlled, executive functions like response inhibition, goal monitoring, and response switching (Anderson et al., 1991; Nielson, Langenecker, & Garavan, 2002). As such, it is plausible that older adults would struggle with a task like think/no-think, which likely relies heavily on such functions.

As described above, inhibition would appear to be a particularly plausible mechanism to explain the no-think suppression effect. It has been suggested that older adults have a specific deficit, relative to young adults, in their ability to inhibit irrelevant information (Hasher, Lustig, & Zacks, 2007; Hasher & Zacks, 1988). This inhibitory deficit has been demonstrated reliably on tasks that require older adults to ignore visually or verbally distracting information (e.g., Connelly, Hasher, & Zacks, 1991; Gazzaley, Cooney, Rissman, & D’Esposito, 2005; Li et al., 1998). If the ability to suppress information on the think/no-think task relies on the ability to inhibit no-think words, then we may expect older adults to have particular difficulty on those no-think trials, relative to younger adults.

Another possible mechanism underlying the think/no-think task is participant-generated interference between the cue and target. As described by several authors (Bauml & Hanslmayr, 2010; Hertel & Calcaterra, 2005; Tomlinson et al., 2009), it is possible that participants self-distract or create new associations for no-think cue words during the experimental no-think trials. As Tomlinson et al. describe, participants may lose the old association between the cue and target, and learn to associate the cue word with something like “sitting still” instead. In this case, participants would not need to rely explicitly on inhibition, but rather could succeed by replacing the to-be-suppressed target with some other response.

Although no study has yet tested older adults on the think/no-think paradigm, Titz and Verhaeghen (2010) have presented a meta-analysis examining the effects of aging on directed forgetting (on either the list-method or item-method tasks). Their results indicate that older adults typically show greater difficulty acquiescing to a forget cue than do young adults, again suggesting that there may be some age-related impairment in intentionally suppressing information. However, several studies have shown evidence that older adults can succeed on a directed forgetting task (e.g., Sahakyan, Delaney, & Goodmon, 2008; Sego, Golding, & Gottlob, 2006; Zellner & Bauml, 2006). These studies (Sahakyan et al.’s in particular) suggest that older adults’ impairment on the directed forgetting task is attenuated when they are given specific strategies to use to follow the forget cue; indeed, the production-deficiency hypothesis (Craik & Byrd, 1982; Mitchell & Perlmutter, 1986) suggests that older adults are poor at generating their own cognitive strategies, but can perform as well as young adults when strategies are given to them. As such, we see that there are several mechanisms that suggest that older adults may have difficulty with the think/no-think task: it may be that they will have difficulty inhibiting no-think words either during the experimental phase or at test, or they may not be able to spontaneously generate appropriate strategies to suppress those words.

However, the think/no-think task differs from directed forgetting tasks in several important ways. First, directed forgetting tasks (particularly the item-method directed forgetting task) typically require manipulation of information that is held in working memory; conversely, the think/no-think paradigm requires manipulation at the storage phase of memory. It may be the case that it is easier for older adults to manipulate information that has already been stored versus information in working memory, therefore enabling them to succeed on the think/no-think task. Additionally, older adults may have difficulty in spontaneously generating strategies to forget information on directed forgetting tasks. While the think/no-think task also does not give older adults specific strategies for reinforcing or suppressing target items, they are told what *not* to do (i.e., not to think of the word on the screen, not to look away from the screen, etc.), and this may help them to hone in on a strategy for success. It has been demonstrated that older adults' performance on cognitive tasks is impaired when specific strategies are not provided (Naveh-Benjamin, Brav, & Levy, 2007), and so it is therefore possible that the think/no-think task will be easier for older adults than directed forgetting tasks because they are given more guidance on strategies to use. Lastly, the think/no-think task does not specify that participants must forget the target words, unlike in directed forgetting paradigms. The think/no-think task may reflect processes aside from strategic forgetting, including retrieval-induced forgetting (Anderson, Bjork, & Bjork, 1994; Aslan, Bäuml, & Pastötter, 2007), which may lead to age effects different from those found under other directed forgetting paradigms. For these reasons, it is possible that despite older adults' impairment on directed forgetting tasks relative to young adults, they may have more success on the think/no-think task.

Experiment 1 was designed to compare the think/no-think effect between a college-age population and an older (aged 65+) population. We used Anderson and Green's (2001) think/no-think procedure, in which participants study pairs of words to criterion, and then are instructed to think about some targets and suppress others, before being given a surprise memory test. We may expect that advancing age would prevent older adults from showing the same magnitude of think/no-think effect as young adults, possibly because of age-related deficits in inhibition and strategy generation. However, it is possible that the requirements of the think/no-think task tap into processes that are relatively preserved in aging, in which case we may expect older adults to perform similarly to young adults. Experiment 1 adjudicated between these alternatives.

Method

Participants

Participants were 26 healthy young adults (14 female) between the ages of 18-30 ($M = 20.43$) and 24 healthy older adults (20 female) between the ages of 65-90 ($M = 75.07$) from the greater Boston area (see Table 1 for participant characteristics). Of the 24 older adults, two were excluded for scoring above a 10 on the Beck Depression Inventory. The final sample size for older adults was 22 (19 female).

Participants were compensated with either course credit, or at a rate of $10/hr. Participants were prescreened for history of psychiatric or neurological disorders, and for current depression or high anxiety. All participants had normal or corrected-to-normal vision. Informed consent was obtained in a manner approved by the Boston College Institutional Review Board.

Design and Materials

Stimuli. There were 80 words selected from the Affective Norms for English Words (ANEW; Bradley & Lang, 1999) word list. Words in the ANEW list are rated for valence on a 1–9 scale (1 being very negative, 9 being very positive) and also rated for arousal on a 1–9 scale (1 being low arousal, 9 being high arousal). Only words rated as "neutral" (with a valence rating between 3.5 and 5.5) were used in this study. Words were randomly paired together into 40 semantically unrelated cue + target pairs (e.g., "card + mouse"). Words did not repeat across study pairs.

Table 1
Participant Characteristics in Experiment 1

	Young adult	Older adult		
Measure	Mean (*SD*)	Mean (*SD*)	*t*	*p*
Beck Depression Inventory	3.00 (3.91)	2.22 (1.93)	0.78	0.44
Beck Anxiety Inventory	4.35 (4.90)	4.94 (5.84)	0.36	0.73
Dex BADS-DEX Questionnaire	12.42 (5.64)	13.89 (7.19)	0.75	0.45
Geriatric Mood Scale	N/A	1.56 (2.68)	N/A	N/A
ERQ reappraisal avg	5.35 (2.36)	5.18 (0.88)	0.49	0.79
ERQ suppression avg	2.72 (0.95)	2.95 (1.20)	0.66	0.52
Shipley Vocabulary Test	32.04 (3.16)	37.73 (1.62)	6.49	<0.01
Digit symbol	50.58 (7.39)	33.75 (9.38)	6.47	<0.01
Digits backward	8.69 (2.38)	7.11 (1.64)	2.44	0.02
Wisconson card sort (categories)	5.81 (0.98)	5.71 (0.47)	0.40	0.69
Wisconsin card sort (errors)	3.73 (6.25)	6.33 (6.12)	1.37	0.18

Note. The Beck Depression Inventory and Beck Anxiety Inventory are from Beck et al. (1988); the Behavioral Assessment of the Dysexecutive Syndrome—Dysexecutive Questionnaire (BADS-DEX) questionnaire is from Wilson et al. (1996); the Geriatric Mood Scale is from Sheikh and Yesavage (1986); the ERQ Reappraisal and Suppression measures are from Gross and John (2002); the Shipley Vocabulary Test is from Shipley (1986); the Digit Symbol Copy and Digits Backward measures are from Wechsler (1997); the Wisconsin Card Sort measures are from Nelson (1976).

Table 2
Participant Characteristics in Experiment 2

Measure	Young adult Mean (*SD*)	Older adult Mean (*SD*)	*t*	*p*
Beck Depression Inventory	3.02 (2.94)	3.22 (2.87)	−0.31	0.76
Beck Anxiety Inventory	3.48 (3.10)	3.57 (3.13)	−0.57	0.57
Dex BADS-DEX Questionnaire	8.08 (5.77)	9.49 (4.76)	−0.96	0.34
Geriatric Mood Scale	N/A	0.88 (0.91)	N/A	N/A
ERQ reappraisal avg	5.06 (0.87)	4.88 (1.31)	0.73	0.47
ERQ suppression avg	3.48 (1.22)	2.30 (1.01)	4.60	<0.01
Shipley Vocabulary Test	32.83 (3.11)	35.51 (2.66)	−4.01	<0.01
Digit symbol	44.95 (7.86)	45.41 (5.70)	−0.29	0.77
Digits backward	8.44 (1.96)	6.97 (2.02)	3.25	<0.01

Stimulus presentation. All three phases of the task were presented on a Macintosh desktop computer, running MacStim 3 software (WhiteAnt Occasional Publishing, http://www.brainmapping.org/WhiteAnt). Words were presented in white text on a black background (for the learning and test phases) and red or green text on a black background (for the experimental phase). All words were presented in the center of the screen, in size 48-point Lucida Grande font.

Procedure

The task was comprised of three phases: a learning phase, an experimental phase, and a test phase. Each phase of the study was preceded by a Practice phase, to assure that the participants understood the task procedure.

Learning phase. Each participant's task was to learn 40 total word pairs. Pairs were presented in four lists of 10 pairs each. Each list consisted of both a study period (during which the participants were asked to learn the pairs) and a cued-recall test period, where recall for target words was tested to ensure adequate learning.

During the study period, word pairs were shown one at a time for 4 s, in the form "[cue word] + [target word]." Pairs advanced automatically after 4 s. Participants were instructed to instructed to use whatever strategy they were the most comfortable with to try and learn the word pairs. During the practice phase, the experimenter suggested that the participant could try putting the words in a sentence (e.g., "Fruit grows in the west" for "fruit + west"), or to picture the items together (e.g., picture an apple on the western part of a map).

Following presentation of the final (10th) word pair in each list, participants were given a cued recall test for the pairs within that list. Participants were shown a single cue word on the screen followed by "+ ?" (e.g., "card + ?"), and were asked to verbally state the corresponding target word (Figure 1a). Responses were recorded on a laptop computer by the experimenter. After each response, the experimenter gave the participant verbal feedback as to whether the response was correct or incorrect. Following this feedback, the participant was instructed to press the spacebar, and the correct cue + target pair was shown for 2 s.

Each participant was required to reach a learning criterion of 60% correct before moving on to the next list. If this criterion was not met, the same study list was repeated. After the participant reached criterion on all four learning lists, they were given a comprehensive cued recall test for all 40 word pairs. This test was structured identically to the shorter test phases described above. Cues were presented in a randomized order. Participants needed to achieve at least 50% criterion on this comprehensive test before moving on to the next phase of the experiment; if the participant did not reach this criterion, the whole of the learning phase was repeated. In this study, all participants reached the 50% criterion on their first attempt.

Experimental phase. During the experimental phase, participants were shown single cue words from 32 of the 40 pairs they had encountered during the learning phase. There were 16 words randomly assigned to the think condition and 16 words were

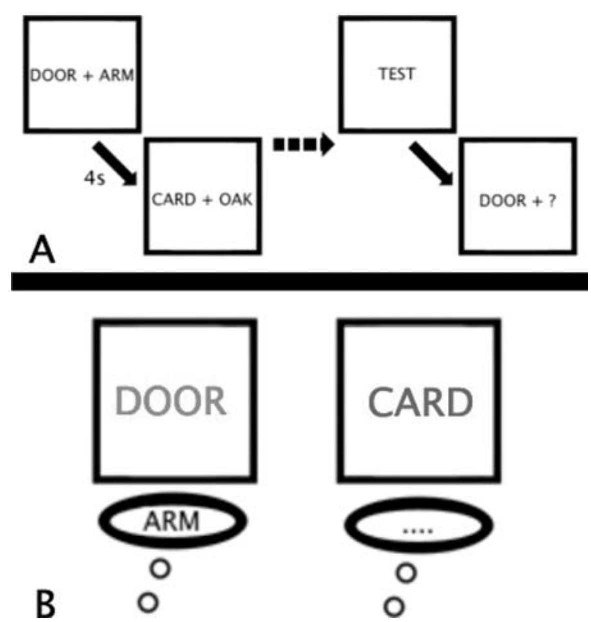

Figure 1. Representation of the learning phase (A) and experimental phase (B) for the three Experiments. Participants studied pairs of unrelated words, and were then tested to ensure learning to criterion (A). The left-hand word of some pairs was then shown in either green or red letters (B). If a word appeared in green, participants were instructed to try and recall the paired associate (e.g., "DOOR + ARM"). If the word was shown in red, participants were instructed to put the paired associate out of mind entirely (e.g., "CARD + . . .").

assigned to the no-think condition. The remaining 8 pairs did not appear at all during this experimental phase and were treated as control pairs. The pairs that were included in the think, no-think, or control conditions were counterbalanced across participants.

Cue words appeared one at a time for 4 s (for young adults) or 6 s (for older adults), in either green or red letters (Figure 1b). Different presentation rates were used for the two age groups because pilot testing revealed that, in the think condition, older adults took longer than young adults to generate the target words. Participants were instructed to think about the target word if the cue appeared in green text and were instructed not to think about the target word if the cue appeared in red text. Participants were explicitly instructed not to look away from the screen during no-think trials and were told to focus on the word on the screen until it disappeared while trying to put its pair out of mind. Each cue appeared a total of six times, for a total of 192 trials, and cues were presented in random order with the caveat that the same cue never appeared more than once in any set of six trials (e.g., after participants saw the word "month," at least five other cues would appear before month was presented again). The same cue always was presented in the same condition, for instance, if month appeared first in green text (think), all subsequent presentations of month would be in green as well. Participants were offered four brief breaks throughout the experimental phase, occurring after every 35 trials. The word "BREAK" appeared on the screen in purple letters, and participants were instructed to press the space bar when they were ready to continue. The experimenter was not present in the room during this experimental phase.

Test phase. The final phase of the study consisted of a cued recall test for all 40 of the originally learned word pairs. The order of cue presentation was randomized so that the test order differed from the order in the learning or experimental phases. Presentation of this phase was identical to the comprehensive test at the end of the learning phase, although participants were not given feedback (either verbal or visual) as to their accuracy. After verbally making their response to a particular cue, they were instructed to press the spacebar to view the next cue word. All responses were recorded on a laptop computer by the experimenter.

Trials included in data analysis. Because we were interested in understanding how the think/no-think manipulation affected participants' abilities to recall words that they had learned successfully, only pairs that participants had learned were included in analyses. Any pairs that the participant did not recall during the comprehensive test at the end of the learning phase were not included in analysis of that participant's results. For example, if a participant recalled 37 out of a possible 40 pairs at the end of the learning phase, only those 37 pairs were scored following the final test. This conditional scoring assured that differences between think and no-think conditions resulted from differences in the processing of information that had been successfully encoded into memory. Unless otherwise noted, all subsequent results presented are based on this conditional scoring method.[1]

Results

There was a significant age difference in the number of pairs originally learned. Following the study phase, younger adults had learned an average of 85.5% [2.3%] of pairs, while older adults had learned 67.5% [3.3%], $t(41) = 4.64$, $p < .01$.

Conditionally scored data (as described above) were submitted to a 3 (condition: think, no-think, control) × 2 (age) mixed-factors ANOVA.

A significant effect of condition was observed ($F(2, 92) = 7.12$, partial $\eta^2 = 0.13$). Paired-samples *t*-tests revealed that, for both age groups, this main effect was driven by the significantly greater recall in the think condition than in the no-think condition, $t(25) = 2.14$, $p = .04$ for young adults and $t(21) = 3.83$ $p < .001$ for older adults. Collapsing across age groups, a significant no-think < control effect was also observed, $t(47) = 2.33$, $p = .02$.

There was a significant main effect of age ($F(1, 46) = 11.86$, partial $\eta^2 = 0.21$), with younger adults recalling significantly more items than older adults (83.8 [3.2%] and 67.4% [3.5%], respectively). Age and condition did not interact. The results of Experiment 1 can be seen in Figure 2 (top left panel).

We also examined whether there was a correlation between our measures of executive function (Digit Symbol, Digits Backwards, and Wisconsin Card Sorting Task) and the think/no-think effect (measured by subtracting no-think recall percentages from think recall percentages). For both age groups, there was no significant correlation between any of the measures of executive function and the magnitude of the think/no-think effect ($r^2_{\text{digit\_symbol}} = 0.05$, $r^2_{\text{digits\_backwards}} = 0.01$, $r^2_{\text{wcst}} = 0.02$). There was also no relationship between these three measures and suppression ability (measured by subtracting no-think scores from control scores; $r^2_{\text{digit\_symbol}} < 0.01$, $r^2_{\text{digits\_backwards}} = 0.02$, $r^2_{\text{wcst}} = 0.02$).

Discussion

Experiment 1 demonstrated that both younger and older adults could perform the think/no-think task. Both age groups recalled significantly fewer words in the no-think condition than in the think condition, and there was also a trend for both age groups, which was revealed as significant when collapsing across age, for no-think words to be recalled below the control baseline. This latter finding is consistent with the results of Anderson and Green (2001).

The critical finding of Experiment 1 was that aging did not interact with the think/no-think instructions. Though older adults initially learned significantly fewer pairs than younger adults and their overall tested recall was lower than that of young adults, older adults were still influenced by the think/no-think manipulation. This result suggests that while there are age differences in the ability to successfully encode and retrieve information, the information that older adults successfully store in long-term memory is available for manipulation in the think/no-think task. This point is highlighted by our choice to analyze data that are conditionally scored: by only analyzing those pairs that participants successfully learned during the study phase, we specifically examine each age group's ability to think about or suppress information that has already been stored in long-term memory. While older adults learn

[1] All analyses were also conducted with all learning trials included in the analysis (all 40 pairs analyzed for both age groups in Experiment 1, and all 80 pairs analyzed in Experiments 2, 3, and 4). The same pattern of results emerged as is reported in the main text, with all four experiments showing a significant think > no-think effect and no-think < control effect, and no interaction between age and condition. For brevity we have not included these data in the manuscript but they are available upon request.

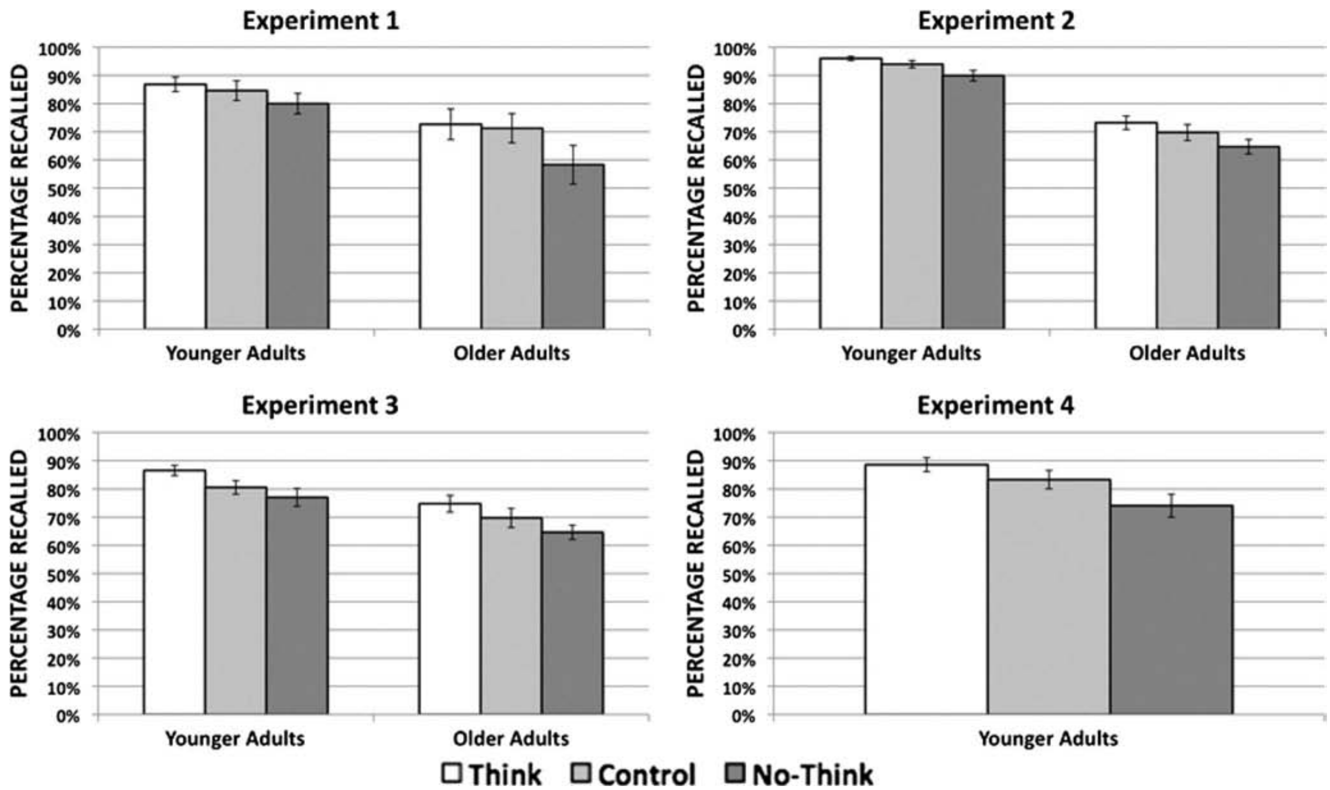

Figure 2. Overall mean recall percentages for think, no-think, and control words, divided by age group and experiment. Data shown are collapsed across emotion (positive, negative, and neutral). Data for Experiment 3 (bottom left) are for the traditional test. Each individual age group shows significantly greater recall for think words than no-think words at the $p = .05$ level. When collapsed across age (not pictured), participants in each experiment show significantly reduced recall for no-think words compared to control words at the $p = .05$ level.

fewer pairs initially, as might be expected, they can still think or "not-think" about the pairs that they do learn as successfully as young adults can.

Although Experiment 1 showed no difference in the ability of older and younger adults to forget neutral information, we wanted to replicate this finding and to examine whether age differences would become apparent if the information being suppressed had some emotional content. It has been proposed that older adults may process emotional information differently than young adults, despite the fact that regions of the brain responsible for emotion processing remain relatively intact with aging (see Chow & Cummings, 2000, for a review). As we discuss below, we may expect that because older and younger adults process emotional information differently from one another, we may observe an age-related interaction between emotion and the think/no-think instructions.

Experiment 2

It has been demonstrated that people process emotional information differently from neutral information (Bradley & Baddeley, 1990; Kensinger & Corkin, 2004), with emotional items typically receiving a benefit in memory. If emotional information is encoded and stored in memory in a more durable fashion than neutral information (and see Hamann, 2001; LaBar & Cabeza, 2006; McGaugh, 2004, for discussion), then this may affect the ease with which the information is strategically forgotten. However, the current literature on emotion's effects on memory does not provide a clear hypothesis for how emotion may affect the think/no-think task.

Depue and colleagues (2006) posed two possible outcomes for the effect of emotion on the think/no-think task. First, it may be the case that emotional items are more difficult to suppress than neutral items, because the memory trace will be stronger for emotional items. In this case, emotional items may not show the same no-think effect that is seen for neutral items. Conversely, as suggested by Norman, Newman, Detre, and Polyn (2004), because emotional memory traces can be more readily accessed than neutral, those traces may be easier to manipulate: either to reinforce or suppress. If this is the case, then emotional items should show disproportionate think and no-think effects, relative to neutral items.

As noted, the literature has been mixed with regard to which of these alternatives is the better account. In two experiments using face-word pairs and face-picture pairs, Depue and colleagues (2006) showed a greater no-think effect for negatively valenced information (regardless of stimulus type) than for neutral information, suggesting that negative items may be easier to suppress. Marx, Marshall, and Castro (2008), however, found that pleasant, highly arousing words showed a greater suppression effect than other emotional stimuli. They did not include neutral stimuli in their assessment, so it cannot be determined from their study whether there was an overall advantage for suppression of the positive as compared to the neutral words, but the contrasting findings of Depue et al. (2006) and Marx et al. (2008) emphasize that the effects of valence on intentional forgetting are unclear. Adding to the mixed findings, Minnema and Knowlton (2008) used a listwise directed forgetting paradigm and found that negative emotion may impair the control processes needed to suppress information. However, Wessel and Merckelbach (2006) found no significant effects of stimulus emotionality on a listwise directed forgetting task. Taken together, these four studies (while using a variety of methodologies) demonstrate a lack of clear understanding for how easily emotional information can be manipulated in memory. As such, one aim of Experiment 2 was to examine whether emotional information is easier or more difficult for young adults to suppress or reinforce in memory than neutral information.

It is also particularly important to consider how aging affects memory suppression for emotional material, given extensive evidence that aging alters the way in which emotional information is processed. Older adults seem to place a greater importance on affect than young adults (Carstensen & Mikels, 2005), and age differences are particularly apparent when controlled processing is examined (i.e., processes that demand attentional resources and require the integration of prior and/or contextual knowledge; Kensinger & Leclerc, 2009; Mather, 2006; St. Jacques, Bessette-Symons, & Cabeza, 2009). Older adults seem to process emotional information in a more top-down, appraisal-based fashion than young adults, and they often show a shift specifically towards the processing of positive over negative information (Isaacowitz et al., 2006; Mather & Carstensen, 2003). Therefore, it has been suggested that older adults may chronically engage emotion regulatory processes (Carstensen, Isaacowitz, & Charles, 1999; Mather & Knight, 2005), requiring the constant appraisal of emotional stimuli. If older adults are more likely than young adults to use attentional resources for this cognitive appraisal of emotional information, this may limit the resources available for the reinforcement or suppression of emotional stimuli presented during the think/no-think phase. For this reason, if there are age differences in the think/no-think task, they might be particularly likely to arise when emotional stimuli are the targets of the experimental manipulation.

Given these age-related changes in emotion processing, how might emotion affect performance on the think/no-think task for older compared to younger adults? It is possible that older adults will show better suppression for emotional items: if older adults process emotional material in a more controlled fashion, as described above, they may be better able than young adults to control memories for emotional material. Alternatively, older adults may have greater difficulty putting emotional information out of mind because of the declines in cognitive control mechanisms described previously. Older adults' attention resources may also be limited because of the chronic appraisal of emotional material, thereby limiting the resources available to perform the think/no-think task. The second aim of Experiment 2 was to investigate if age interacts with the ability to suppress emotional versus neutral material.

Method

Participants. Participants were 41 healthy young adults (21 male), between the ages of 18–30 (M = 20.82), and 37 healthy older adults (17 male) between the ages of 65–90 (M = 72.16). Young and older adults met the same criteria as in Experiment 1, and were compensated in the same manner. No one who participated in Experiment 2 also participated in Experiment 1. Participants characteristics for Experiment 2 can be seen in Table 1. Materials and methods were approved by the Internal Review Board of Boston College.

Design and materials.

Stimuli. There were 200 words selected from the ANEW (Bradley & Lang, 1999) word list. Of the selected words, 40 were positively valenced (valence > 6.5, M = 7.62), 40 were negatively valenced (valence < 3.5, M = 2.76), and 120 were neutral (M = 5.19). Critical to this study, positive and negative words were matched on arousal (M = 5.99 and 6.05, respectively) to isolate the effects of emotion. The mean arousal for neutral words was 3.99. The selected words had also been rated in a comparable fashion by young and older adults (from Kensinger, 2008), we only included words that had been rated as positive, negative, or neutral both by young and older adults.

Words were combined to create 40 "neutral word + valenced word" pairs, and 40 "neutral word + neutral word" pairs. For the former word pair type, valence was a between-subjects manipulation, such that half of the participants learned neutral + positive word pairs, and half learned neutral + negative word pairs. Neutral cue words were counterbalanced to create two sets of 80 pairs in the negative condition, and two sets of 80 pairs in the positive condition (e.g., some participants in the negative condition may learn "card + devil" and "door + arm," while others would learn "door + devil" and "card + arm").

Stimulus presentation. Presentation parameters for Experiment 2 were identical to those of Experiment 1.

Procedure. The procedure for all three phases of Experiment 2 was identical to the procedure for Experiment 1, with the following numerical differences: participants studied 80 word pairs (40 neutral-valenced pairs, 40 neutral-neutral pairs) rather than 40; the experimental phase consisted of 32 think words and 32 no-think words, with a total of 384 repetitions (16 words were not presented and served as control words); the final test phase tested participants on all 80 word pairs.

Trials included in data analysis. Each participant's think/no-think data were scored conditionally, as described in Experiment 1.

Results

There was a significant main effect of age in the number of initially learned pairs (pairs the participant recalled correctly following the learning phase), $t(76) = 4.01$, $p < .01$. Younger adults learned an average of 75.3% [1.7%] of pairs. Older adults learned an average of 65.4% [1.8%] pairs. There was no effect of target emotionality (emotional, neutral), or of emotional valence (positive, negative) on the number of pairs learned initially. Emotional valence condition (whether participants studied positive targets or negative targets) also did not interact with any other factors (all partial $\eta^2 < 0.02$), and so this between-subjects factor was not included in the ANOVA reported below. The data for Experiments

2-4, divided by valence (positive, negative, and neutral), can be seen in Appendix A (supplementary material available online only).

Data were submitted to a 3 (condition: think, no-think, control) × 2 (target emotionality: emotion, neutral) × 2 (age: young, old) repeated-measures ANOVA.

There was a significant main effect of age observed ($F(1, 74) = 101.27$, partial $\eta^2 = 0.58$), with younger adults recalling significantly more words (93.7% [1.6%]) than older adults (69.6%, [1.7%]).

As in Experiment 1, there was a significant main effect of condition ($F(2, 148) = 12.64$, partial $\eta^2 = 0.15$). Paired-samples *t*-tests confirmed that this effect was driven by significantly greater recall for think (85.2 [1.2%]) than no-think (78.1% [1.5%]) items, $t(77) = 4.56$, $p < .01$ (Figure 2, top right panel). For young adults, this effect was significant for the neutral items, $t(40) = 2.47$, $p = .02$, and both positive and negative items showed a statistical trend for think > no-think, $t(20) = 1.84$, $p = .08$ and $t(19) = 1.82$, $p = .08$, respectively. For older adults, the effect of think > no-think was significant for the neutral and negative categories, $t(36) = 2.54$, $p = .02$ and $t(17) = 4.04$, $p < .01$, respectively, and was a trend for positive items, $t(18) = 1.99$, $p = .06$.

There was no significant main effect of the emotionality (emotion vs. neutral; $F(1, 148) = 0.15$, $p = .70$, partial $\eta^2 < 0.01$), nor was there a main effect of valence condition (positive vs. negative; $F(1, 74) = 0.001$, $p = .97$, partial $\eta^2 < 0.01$). Mean recall percentages, separated by the emotionality of the to-be-forgotten word, can be seen in Table 5.

Critically, and consistent with Experiment 1, there was no significant interaction between age group and study type ($F(2, 148) = 1.35$, $p = .26$, partial $\eta^2 = 0.02$). No other interactions reached significance, all $p > .10$ and partial $\eta^2 < 0.01$.

Discussion

Experiment 2 replicated the results of Experiment 1: both young and older adults demonstrated the ability to control the contents of their memories. Critically, the two age groups could suppress both neutral and valenced information, and did not differ significantly in their ability to do so. The emotionality of the information, whether it was emotional or neutral, had no significant effect on task performance for either age group. As can be seen in Figure 2 (top right panel), there was no evidence that older adults suppressed information differently than young adults even when emotional information was included, despite literature that suggests that older adults process emotional information differently than young adults (Mather, 2006; St. Jacques, Bessette-Symons, & Cabeza, 2009). The implications of this finding will be expanded on in the General Discussion.

Consistent with Experiment 1, older adults encoded and recalled fewer total pairs than young adults. Older adults' reduced associative learning and recall is consistent with previous literature (Crawford et al., 2000; Grady, 2008; Souchay, Isingrini, & Espagnet, 2000) and suggests that while age-related declines may affect the quantity of information that can be successfully remembered at one time, the ability to manipulate information that is successfully learned is still evident in older adults.

Taken together, Experiments 1 and 2 offer strong evidence that older adults do not show impairment in suppressing words when directed to, relative to younger adults. However, the mechanism(s) by which this result is achieved is still unclear, and it is possible that the two age groups are using different mechanisms to achieve success. For example, it may be the case that, as suggested by Hasher and colleagues (1999), older adults are impaired relative to young adults at inhibiting unwanted information. Younger adults may therefore be relying on inhibition to successfully suppress no-think words, while older adults may be using some other mechanism, self-distracting during the no-think experimental trials, for example, or creating new associations for the cue word, to effectively block the old target word. Of course, this latter possibility may be the case not just for older adults, but for both age groups. It is possible that if participants learn the pair "INSECT + ACORN," the inability to recall ACORN when cued with INSECT may reflect forgetting of the association between the two words, rather than suppression of ACORN. It is also possible that the cued recall test is not a sensitive enough measure to detect whether a word has truly been suppressed or not, and that probing memory in a different way may yield different results. For example, Castel, Farb, and Craik (2007) showed that older adult participants still had access to to-be-ignored information when their memory was probed through multiple avenues. This is consistent with previous work showing that older adults typically have more difficulty than young adults in ignoring task-irrelevant information (e.g., ignoring irrelevant text in a passage; Connelly, Hasher, & Zacks, 1991). In Castel, Farb, and Craik (2007), older and younger adults studied lists of words that were assigned different point values and were told to try and maximize their score on a recall test by recalling the words with the highest point values. While both groups showed better recall for high point-value than low point-value words, older adults were shown to have actually encoded the low point-value (analogously, the "to-be-ignored") words when their memory was probed via recognition instead of recall. Young adults showed no such effect. In this study, the authors suggest that older adults showed impairment, relative to young adults, in disregarding to-be-ignored information, which would be consistent with an inhibitory deficit in older adults.

The results of Castel, Farb, and Craik (2007) suggest that in our present paradigm, older and younger adults may demonstrate different think/no-think ability if their memory is tested in some way other than cuing the target work with its studied pair. Older adults may still have access to the no-think items, for instance, even though they cannot generate them when cued in this way, whereas young adults may have more effectively suppressed the items. To test this possibility, we used the "independent probe" manipulation used by Anderson and Green (2001). In addition to the cued recall test used in Experiments 1 and 2, we also tested participants' memories for the target words by using semantically related, but previously unstudied, cue words. If memory for the target word was truly suppressed by younger and older adults on the no-think task, then retrieval of the no-think target words should be lower than the retrieval of the other target words in both age groups, even when cued by the independent probe. If, by contrast, older adults retain a stronger trace of the no-think items than young adults, perhaps because of difficulty inhibiting access to those items, then older adults should be more likely to generate the no-think target when cued with an independent probe. Experiment 3 tested these alternatives.

Experiment 3

Experiment 3 tested recall memory in two ways: using the episodic cue, and using words that were semantically related to the target, but previously unstudied. If memory for the target word is suppressed in the no-think condition, then participants should have difficulty retrieving the word in response to either the episodic cue or the semantic associate (discussed in Anderson & Green, 2001). The learning and experimental phases of Experiment 3 were identical to those of Experiment 2; only the retrieval phase differed.

Method

Participants. Participants were 20 healthy young adults (8 male), between the ages of 18-30 ($M = 19.8$), and 20 healthy older adults (13 male) between the ages of 65-85 ($M = 74.1$). Young and older adults met the same criteria as in Experiment 1, and were compensated in the same manner. No one who had participated in Experiments 1 or 2 also participated in Experiment 3. Participant characteristics for Experiment 3 can be seen in Table 3.

Design and materials. The same stimuli from Experiment 2 were used for Experiment 3, with the addition of 80 "probe" words used for the probe test. Probes were obtained from the Edinburgh Word Association Thesaurus (http://www.eat.rl.ac.uk/). Probes were selected if they generated the stimulus target word as an associate in between 10-20% of Thesaurus respondents, and only if they did not generate any of the other stimulus target words as associates (e.g., the probe "HOLIDAY" generated the target "VACATION" in 14% of respondents, but did not generate any of the other 79 target words).

For the probe test, participants would see the probe word paired with the first letter of the appropriate target word (e.g., "HOLIDAY + V . . .").

Procedure. The procedure for Experiment 3 was identical to the procedure for Experiment 2, with the inclusion of the probe test. Participants were given the probe test either immediately before the traditional test, or immediately after it. The order of the two tests was counterbalanced between participants.

Before the probe test, participants were told they would be tested using words that were not previously studied, but that were related in some way to the second word in the pairs they had studied. Participants were given a brief practice using the practice words from the learning phase (e.g., "OAK + A . . ." for the studied pair "INSECT + ACORN"). Once it was clear participants understood the task, they were given the probe test.

Trials included in data analysis. Both the traditional and probe tests were scored conditionally, as described in Experiments 1 and 2.

Results

Data were initially submitted to a 3 (condition: think, no-think, control) × 2 (test type: traditional test, probe test) × 2 (emotionality of target: emotion, neutral) × 2 (valence condition: positive, negative) × 2 (age: young, old) × 2 (order: probe first, probe second) mixed factors ANOVA, with order, age, and valence as between-subjects factors. No main effect of order was observed ($F(1, 32) = 0.21$, $p = .65$, partial $\eta^2 = 0.01$), nor was a main effect of valence ($F(1, 32) = 0.88$, $p = .36$, partial $\eta^2 = 0.03$). Neither factor interacted with any other factors. As such, the data were re-analyzed as a 3 (condition) × 2 (test type) × 2 (emotionality) × 2 (age) mixed factors ANOVA. As in Experiment 2, there was no difference in recall for neutral words that were paired with positive words versus neutral words paired with negative words. All subsequent analyses collapse neutral words from these two conditions together.

While no significant main effect of age was observed, there was a trend revealed, with older adults recalling fewer items (68.2% [1.4%]) than young adults (72.0% [1.4%]), $F(1, 38) = 3.76$, $p = .06$, partial $\eta^2 = 0.09$.

Consistent with Experiments 1 and 2, a significant main effect of condition was observed ($F(2, 76) = 14.34$, partial $\eta^2 = 0.27$), with no-think words showing lower recall (65.7% [1.2%]) than either think (74.0% [1.5%]) or control (70.6% [1.3%]) words. Critically, this effect did not interact with test type ($F(2, 76) = 0.78$, $p = .46$, partial $\eta^2 = 0.02$), indicating that the same pattern of results was observed on both the traditional and probe tests.

A significant main effect of test type was observed as seen in Figure 2 (bottom left panel) ($F(1, 38) = 32.28$, partial $\eta^2 = 0.46$), and this effect interacted significantly with age ($F(1, 38) = 13.84$, partial $\eta^2 = 0.27$). Paired-samples *t*-tests revealed that young adults recalled significantly more words on the traditional test (81.7% [1.7%]) than on the probe test (62.3% [1.9%]), $F(1, 19) = 53.32$, partial $\eta^2 = 0.74$, while older adults' recall did not differ between the traditional test (70.2% [2.5%]) and the probe test (66.2% [2.0%]), $F(1, 19) = 1.64$, $p = .22$, partial $\eta^2 = 0.08$.

Table 3
Participant Characteristics in Experiment 3

Measure	Young adult Mean (*SD*)	Older adult Mean (*SD*)	*t*	*p*
Beck Depression Inventory	2.55 (3.30)	3.70 (2,74)	−1.20	0.24
Beck Anxiety Inventory	3.01 (2.27)	2.99 (3.01)	0.10	0.91
Dex BADS-DEX Questionnaire	9.18 (6.71)	10.73 (5.33)	−1.12	0.27
Geriatric Mood Scale	N/A	1.00 (0.86)	N/A	N/A
ERQ reappraisal avg	4.89 (0.92)	4.94 (1.21)	−0.13	0.90
ERQ suppression avg	3.19 (1.08)	2.44 (1.20)	2.06	0.05
Shipley Vocabulary Test	31.80 (3.50)	35.65 (2.91)	−3.78	<0.01
Digit symbol	45.79 (7.76)	45.35 (6.36)	0.19	0.85
Digits backward	8.45 (1.67)	7.25 (1.77)	2.20	0.03

A significant main effect of emotion was observed ($F(1, 38) = 12.75$, partial $\eta^2 = 0.25$), with emotional words recalled better than neutral words (72.4 [1.0%] and 67.8% [1.4%], respectively). This effect interacted with test type ($F(2, 76) = 13.23$, $p < .01$, partial $\eta^2 = 0.26$), with more emotional words recalled than neutral words on the probe test (69.5 [1.6%] vs. 59.0% [2.0%]) but not on the traditional test (75.3 [1.6%] vs. 76.5% [1.9%]). The results of the traditional test are therefore consistent with Experiment 2, in that no effect of emotion is observed for that test. There were no further interactions revealed. Thus, although emotional items were more likely to be recalled on the probe task than were neutral items, this effect was not influenced by the experimental condition, and it was not influenced by age. The recall data for both the traditional and probe tests can be seen in Table 5. No other influences of emotion or age were revealed, all $p > .10$ and partial $\eta^2 < 0.03$.

Discussion

The absence of age effects on the traditional test in Experiment 3 replicated the results of Experiments 1 and 2: both age groups recalled significantly fewer words from the no-think condition than from the think or control conditions. The emotion results of the traditional test in Experiment 3 replicated those of Experiment 2, with no difference in suppression for positive, negative, and neutral items. These results, taken together with those of Experiments 1 and 2, offer further evidence that the ability to suppress information remains present across the lifespan and can occur regardless of the valence of the to-be-forgotten information.

The critical finding from Experiment 3 was the lack of an interaction between test type (traditional, independent-probe) and condition (think, no-think, control). As is evident from Table 5, even when participants were cued with a word that is semantically related to the target word (and shown the first letter of the target word), they still recalled significantly fewer words from the no-think condition. This result is consistent with Anderson and Green's (2001) proposal that participants' efforts during the no-think condition do not simply break the associative link between the cue and the target but rather suppress the representation of the target word itself, making it less likely to be retrieved via any route. Additionally, the results of the independent probe task suggest that a blocking or interference strategy during the no-think trials is not sufficient to explain the forgetting effects we observe. If participants were blocking the target word by rehearsing new associations for the red, no-think cue word, those new associates should only lead to suppression of the no-think word on the traditional test, when the original cue is present. The semantic probe would not cue those new associates during the independent probe task, and we would therefore not see suppression on the independent probe task. Since we observe significant suppression effects on the independent probe task, this suggests that participants are not relying exclusively on blocking as a strategy for suppression. This finding offers evidence that young and older adults are indeed suppressing the episodic representation of the studied word form memory.

Though Castel, Farb, and Craik (2007) showed that older adults were more likely than young adults to have access to to-be-ignored information, our results suggest that is not the case on the think/no-think task. In addition to the differences discussed in the Introduction between the think/no-think and directed forgetting paradigms, the disparity between our results and Castel, Farb, and Craik's may also be because their task assigns value to each study item *during encoding*, which may lead to age-related differences in strategy or motivation to encode items. For example, young adults may direct encoding resources towards the high value items, while older adults may try to maximize their score by encoding as many items as possible. Related to this point, there are time-course differences in when the memory control needs to occur. In the think/no-think task, all items are equally important for remembrance during study, and it is not until after items have been encoded into long-term memory that they are assigned the think or no-think values. This difference is maximized by the fact that we have chosen to analyze only those pairs that participants successfully encoded.

Although emotion did not interact with condition in Experiment 3, it is interesting that emotion *did* interact with test type, with more emotion words than neutral words recalled on the probe test but not on the traditional test. This result may relate to the inherent semantic relatedness of emotional items. Talmi and Moscovitch (2004) suggest that emotional words are more semantically relatable than neutral words (see also Brainerd et al., 2008). If emotional items have stronger semantic categorizations than neutral items, then this could explain why the semantically related cues used in the probe test were more effective at guiding retrieval of emotional items compared to neutral items (although the associative strength of the cue-target pairs was equated for emotional and neutral target words, according to normative data). However, what is crucial to bear in mind is that although emotional items show higher recall than neutral items *overall* on the probe test, they still exhibit a significant suppression effect. Thus, even though participants more readily recalled emotional items when cued with a semantically related probe, those emotion words were still subject to active suppression. Indeed, the three-way interaction between test type, emotion, and condition was not significant.

Age interacted with test type, such that younger adults performed better on the traditional test than on the probe test, while older adults' performance on the two tests did not differ. One possibility is that this is a result of encoding specificity, described by Tulving and Thompson (1973), decreasing with aging. It is commonly revealed that older adults retain "general" or "gist" representations of studied items, while losing information about the specific context in which the items were studied (Kensinger & Schacter, 1999; Koutstaal, 2003). In the present study, the degradation of the item-specific context may explain why older adults show similar retrieval rates when target words are cued by nonstudied semantic associates or by the studied cue words. Older adults may not benefit as much as young adults from the reinstantiation of the study context (i.e., the cue word), because they do not retain as specific a record of that context in their memory representation as young adults do. Young adults, by contrast, may benefit from the reinstantiation of that context because it is preserved in their memory. This suggestion would be consistent with research by Puglisi et al. (1988), demonstrating that older adults' encoding specificity is especially limited when the task being performed is cognitively taxing. In their study, older adults' encoding specificity for verbal information decreased under a divided attention condition; in our study, the think/no-think task may have created a similar cognitive demand.

While Experiments 1–3 show no interaction between age and the think/no-think effect, we cannot rule out the possibility that older and younger adults are exerting control over memories with different strengths. It is plausible that younger adults encode memories that are of a greater strength than older adults, and this may mean that younger adults need to work harder than older adults to suppress those memory traces during the experimental session. Younger and older adults may not show different think/no-think results during the test phase, but it is possible that because of differences in the strength of the encoded memories, younger adults have to exert more cognitive effort to achieve that result.

One way to test this hypothesis under the current paradigm is to try and equate depth of processing between the age groups. If younger adults spend more time than older adults during learning trials elaborating on their associations, then speeding the encoding trials to 2 s (rather than 4 s) for young adults should weaken their depth of encoding to a level that would be more comparable to older adults. Thus, by comparing the performance of young adults with speeded encoding to the performance of older adults with slower encoding, we could determine whether age differences in the ability to manipulate memory traces would be revealed when the depth of encoding was better matched across the two age groups. If older adults succeed in suppressing memories because their traces are typically weaker (and easier to suppress) than young adults, then we would expect to see age differences (with young adults suppressing better than older adults) if both groups are asked to suppress relatively weaker memory traces. Experiment 4 tested 20 young adults on the think/no-think task, with only 2 s to encode each pair during learning and compared their performance to that of the older adults in Experiment 3.

Experiment 4

Method

Participants. Participants were 22 healthy young adults (10 male), between the ages of 18-30 ($M = 19.2$). Young adults met the same inclusion criteria as in Experiments 1-3 and were compensated in the same manner. No one who had participated in Experiments 1, 2, or 3 also participated in Experiment 4. Two participants were excluded for scoring above a 10 on the Beck Depression Inventory. The final sample size was 20 participants (9 male). Participant characteristics for Experiment 4 can be seen in Table 4.

Design and materials. The same materials were used for Experiment 4 as were used in Experiment 3.

Procedure. The procedure for Experiment 4 was identical to that of Experiment 3, though each word pair during the learning phase was presented for 2 s (as opposed to 4 s in the previous experiments).

Trials included in data analysis. Both the traditional and probe tests were scored conditionally, as described in Experiment 3.

Table 4
Participant Characteristics in Experiment 4

Measure	Young adult Mean (*SD*)
Beck Depression Inventory	3.17 (3.25)
Beck Anxiety Inventory	5.00 (5.12)
Shipley Vocabulary Test	30.79 (3.30)
Digit symbol	48.23 (7.89)

Results

Nearly all participants had to repeat at least one list during the learning phase, with participants needing to repeat 2.55 [0.29] out of four learning lists on average, which was comparable to the number of repetitions required by the older adults. Only one participant did not need to repeat any of the learning lists. All 20 participants still reached the 50% criterion on the fifth, cumulative learning list.

Test data were initially submitted to a 3 (condition: think, no-think, control) $\times$ 2 (test type: traditional test, probe test) $\times$ 2 (emotionality of target: emotion, neutral) $\times$ 2 (valence condition: positive, negative) $\times$ 2 (order: probe first, probe second) mixed factors ANOVA, with order and valence condition as between-subjects factors. As in Experiment 3, no main effect of order was observed ($F(1, 18) = 1.63$, partial $\eta^2 = 0.08$), nor was there a main effect of valence ($F(1, 18) = 1.28$, partial $\eta^2 = 0.07$). Neither factor interacted with any other factors. As such, the data were re-analyzed as a 3 (condition) $\times$ 2 (test type) $\times$ 2 (emotionality) repeated-measures ANOVA.

A significant main effect of condition was again observed ($F(2, 38) = 19.52$, partial $\eta^2 = .55$). This can be seen in Figure 2 (bottom right panel). Paired-samples *t*-tests revealed that this effect was driven on the traditional test by a think > no-think effect, $t(19) = 5.3$, $p < .001$, a think > control effect, $t(19) = 2.09$, $p = .05$, and by a no-think < control effect, $t(19) = 4.66$, $p < .001$. On the probe test, the main effect was driven by a think > no-think effect, $t(19) = 3.87$, $p = .001$ and by a no-think < control effect, $t(19) = 2.29$, $p = .03$. Critically, as in Experiment 3, the main effect of condition did not interact with test type ($F(2, 38) = 0.37$, partial $\eta^2 = 0.02$).

As in Experiment 3, a significant main effect of test type was observed ($F(1, 19) = 19.52$, partial $\eta^2 = 0.51$), with participants recalling significantly more words on the traditional test (82.0% [3.0%]) than on the probe test (64.7% [2.2%]).

Also consistent with Experiment 3, a significant main effect of emotion was observed ($F(1, 19) = 5.43$, partial $\eta^2 = 0.22$), with significantly more emotion words (75.8% [1.6%]) recalled than neutral words (70.9% [2.5%]). This effect is qualified by a significant interaction between emotion and test type, with equal recall for emotional and neutral words on the traditional test (81.0 [2.7%] and 83.0% [3.8%]), respectively) but significantly better recall for emotion words than neutral words on the probe test (70.5 [2.6%] and 58.8% [2.6%], respectively).

We also compared the young adults' performance in this task to the older adults' performance in Experiment 3. As in Experiment 3, test type interacted significantly with age ($F(1, 38) = 7.00$, partial $\eta^2 = 0.16$), with young adults showing a greater magnitude of difference in recall between the traditional and probe tests (82.0 [2.7%] and 64.7% [2.2%], respectively) than older adults (70.2% [2.7%] on the traditional test and 66.2% [2.2%] on the probe test). Age did not interact with any other factors, and no other interactions reached significance, all $p > .10$ and partial $\eta^2 < 0.04$. Data for all experiments can be seen in Table 5.

Discussion

Experiment 4 aimed to address the possibility that older and younger adults differed in their depth of processing on the first three Experiments and that this could have masked age differences in suppression ability. If, in the earlier experiments, young adults were able to create a mental image more quickly than older adults, more of their encoding time could have been spent elaborating on their representation of the pair. Age differences may not have been apparent in the prior experiments because older adults were suppressing weaker memory traces than young adults, and these weaker traces may have been easier to manipulate. The results of Experiment 4, however, provide no evidence to support this interpretation. By speeding the encoding trials in Experiment 4, young adults had less time for elaboration. However, even when young adults' depth of processing was limited in this way, we still did not find any difference in the think/no-think effect between these younger adults and the older adults given a longer encoding opportunity. This finding suggests that the lack of age differences may not arise simply because older adults are suppressing weaker (and easier to manipulate) traces than young adults.

Speeding the presentation succeeded in making the encoding task a more difficult one for young adults. Young adults on average needed to repeat more than half of the learning lists to achieve the 60% criterion required for each individual list, although all young adults reached the 50% criterion required on the compiled, final list on their first attempt. With the slower encoding used in the prior experiments, young adults needed to repeat very few learning lists. The level of repetition needed by the young adults in Experiment 4 is on par with the learning performance of older adults in the previous experiments, suggesting that the manipulation was successful in creating a more age-invariant encoding process.

In general, the results of Experiment 4 replicated the results of Experiment 3, with significantly below-baseline recall of no-think words and above-baseline recall for think words on the traditional test (though this latter effect was not observed for the semantic probe test) and with no effect of age on the magnitude of these

Table 5
Mean Recall Rates (SE) for All Experiments

	Think	Control	No-Think
Experiment 1			
YA	86.8 (2.6)	84.6 (3.5)	80.0 (3.6)
OA	72.7 (5.4)	71.2 (5.2)	58.3 (6.9)
Experiment 2			
YA			
Emotion	95.5 (0.9)	92.3 (2.5)	90.3 (2.3)
Neutral	96.9 (1.0)	94.7 (1.5)	92.5 (1.7)
OA			
Emotion	75.1 (2.3)	70.6 (3.3)	64.8 (2.7)
Neutral	73.2 (3.1)	69.1 (3.5)	65.0 (3.1)
Experiment 3 (traditional)			
YA			
Emotion	86.3 (1.8)	81.4 (2.4)	76.4 (2.5)
Neutral	86.3 (2.7)	80.5 (3.7)	79.1 (3.9)
OA			
Emotion	76.4 (3.0)	66.4 (3.4)	65.1 (2.5)
Neutral	73.0 (3.7)	72.8 (4.2)	67.5 (3.9)
Experiment 3 (probe)			
YA			
Emotion	69.9 (2.4)	71.9 (3.2)	63.3 (2.2)
Neutral	60.5 (4.0)	55.0 (4.5)	53.4 (3.4)
OA			
Emotion	74.0 (3.2)	75.8 (2.9)	62.2 (2.4)
Neutral	65.9 (4.9)	60.8 (5.3)	58.3 (3.4)
Experiment 4 (traditional)			
YA			
Emotion	88.6 (2.6)	83.1 (3.2)	71.4 (3.6)
Neutral	88.5 (2.9)	84.0 (4.1)	67.1 (5.3)
Experiment 4 (probe)			
YA			
Emotion	74.6 (2.5)	73.6 (4.4)	59.0 (4.0)
Neutral	64.0 (3.2)	61.7 (5.1)	47.8 (4.0)

differences. Moreover, young adults' overall recall performance was still quite good over the long term, and better than older adults' performance in Experiment 3. This finding supports our earlier assertion that the most pronounced effect of age on the think/no-think task is on the ability for information to be successfully remembered over the long term, rather than on the ability for learned information to be manipulated in memory.

General Discussion

Data from four experiments using a think/no-think task have demonstrated that young and older adults can succeed on a think/no-think task, consistently showing below-baseline recall for no-think words and significant difference in recall for think over no-think words (see Table 6). This effect does not interact with age or valence, and the results of the independent-probe tasks suggest that the impaired recall of no-think words is supposed to suppression of the target word and cannot be explained entirely by another mechanism like blocking or un-learning of the cue-target association.

This set of experiments suggests that there may be important distinctions in the mechanisms that influence the quantity of information that can be learned and that influence the manipulability of the learned knowledge; that is, how we can edit our memory for information that has successfully made it into our long-term stores. Older adults' overall recall levels were lower than those of young adults, but their ability to "think about" or suppress learned information did not differ from young adults. The implication of this result is that although aging may impair older adults' ability to successfully encode and retrieve information, it may not impair older adults' ability to exercise control over the information that is successfully encoded. This is a promising direction for future inquiries using neuroimaging: older adults may show the same recruitment of frontal activity reported by Anderson et al. (2004) and Depue et al. (2006, 2007), indicating that the inhibitory processes supporting memory suppression are still available in older age. Alternatively, older adults may show recruitment of other compensatory regions that support memory suppression.

The results also show that the think/no-think effect does not always interact with the emotionality of the information to be reinforced or suppressed. Although emotional information is often preferentially processed and remembered (e.g., Hamann, 2001), the resiliency of emotional memories does not have to make them less (or more) susceptible to the effects of volitional suppression. The present results add to a growing literature (e.g., Depue et al., 2006; Marx et al., 2008) suggesting that emotional information is available to cognitive manipulation and is not rigidly fixed in memory. Moreover, by using the independent-probe task as well as the traditional cued recall task, the present results reveal that this strategic forgetting can reflect active suppression of an emotional target memory.

The fact that older and younger adults do not differ on these suppression measures suggests that the way in which emotional information is processed (in a controlled vs. in a more automatic fashion) may not have a large influence on its ability to be suppressed. It has previously been shown that depressed or dysphoric individuals, who tend to perseverate on negative information, still show standard directed forgetting effects on list-type tasks (Power et al., 2000; Wong & Moulds, 2007), despite the fact that they show heightened sensitivity to, and encoding of, negative information. In the present study, older adults, who often process emotional (and sometimes specifically positive) information in a more controlled fashion than young adults (Mather & Knight, 2005), did not differ from young adults in suppressing that information from memory.

Our results are reconcilable with other directed forgetting paradigms (particularly the item-method directed forgetting paradigms) that have previously demonstrated impaired directed forgetting with age (Collette et al., 2009; Hogge, Adam, & Collette, 2008; Zacks, Radvansky, & Hasher, 1996; see Titz & Verhaeghen, 2010, for a meta-analysis). As we discuss in the earlier, it may be that it is more difficult for older adults to suppress information

Table 6
Paired-Sample Condition Comparisons for All Experiments

Experiment	T > NT	T > C	NT < C
Experiment 1, combined	Yes	No	Yes
Experiment 2, combined	Yes	Yes	Yes
Experiment 3 traditional, combined	Yes	Yes	Yes
Experiment 3 probe, combined	Yes	No	Yes
Experiment 1, YA	Yes	No	No
Experiment 1, OA	Yes	No	Yes
Experiment 2, YA	Yes	No	$p = .08$
Experiment 2, OA	Yes	$p = .09$	Yes
Experiment 3 traditional, YA	Yes	$p = .07$	No
Experiment 3 traditional, OA	Yes	No	No
Experiment 3 probe, YA	Yes	No	No
Experiment 3 probe, OA	Yes	No	No
Experiment 4 traditional	Yes	Yes	Yes
Experiment 4 probe	Yes	No	Yes

Note. Paired-sample *t*-test results for each of the experiments, comparing the think, no-think and control conditions, collapsed across emotion. T = think; NT = no-think; C = control; YA = young adult; OA = older adult; combined = data collapsed across age groups. Yes indicates that the comparison was significant. A listed *p*-value indicates that the comparison was not significant at the $p = .05$ level but showed a trend towards significance. Only young adult data was collected for Experiment 4.

from working memory (as in item-method directed forgetting tasks) than from long-term memory (as in the think/no-think paradigm). Indeed, Titz and Verhaeghen note in their meta-analysis that list-method directed forgetting tasks, which are more reliant on long-term episodic than working memory, often show equivalent performance for young and older adults. Additionally, the ambiguity of forget instructions in directed forgetting tasks may make it more difficult for older adults to narrow in on an appropriate strategy for success, while instructions on the think/no-think task offer more constraints (e.g., participants are told not to look away form the screen, not to let the target word enter consciousness, etc.) that may make strategy generation easier. Lastly, unlike directed forgetting paradigms, the think/no-think instructions to not specifically require participants to forget learned information, and therefore think/no-think may reflect mechanisms other than strategic forgetting (such as retrieval-induced forgetting[2]).

We acknowledge several possible limitations of the presented set of studies. First, as a result of only conditionally analyzing our data (excluding those trials that participants did not initially learn), we may be facing scaling issues between our age groups. Older adults did initially encode significantly fewer pairs than young adults in Experiments 1 and 2, which could artificially inflate the magnitude of older adults' think/no-think effect. However, while older adults' set sizes are significantly smaller than those of young adults, we do not think they are sufficiently reduced to skew the overall results in any meaningful way (older adults learned approximately seven fewer words than young adults in Experiment 1, eight fewer in Experiment 2, three fewer in Experiment 3, and five fewer than young adults learned in Experiment 4). We suggest that this conditionalized analysis method is a more accurate measure of suppression than including all trials in the analysis, because as discussed in the introduction, the inclusion of all trials can conflate the failure to encode with the ability to suppress. Nevertheless, as noted in Footnote 1, re-analyzing the data with all trials included does not change the overall pattern of results we are reporting, suggesting that our findings are not a spurious result of reliance on the conditionalized scores.

Additionally, future research will be needed to clarify the processes underlying the think/no-think effects revealed here in each age group. These behavioral data suggest that there are several processes (blocking or un-learning of associations) that cannot fully explain the forgetting results we observe on the traditional and probe tests. However, it is still unclear what specific mechanisms *do* underlie the think/no-think effects for both age groups. Again, this appears to be fertile ground for a neuroimaging investigation, which may help to further elucidate how older and younger adults succeed at this task.

Our results demonstrate that older and younger adults do not differ in their ability to suppress previously learned episodic information on a think/no-think task. As null findings may raise concerns that our paradigm lacks power to detect group differences, we have performed a series of power analyses to show that our paradigm would have had sufficient power (greater than 0.80) to detect any critical interactions. Across the first three Experiments (where age $\times$ condition was a factor), the analysis revealed that we would have had the ability to detect an age by condition interaction with an effect size of Cohen's $f = 0.07$. We also would have had power to detect an age by emotion interaction across Experiments 2 and 3 (where age $\times$ emotion was a factor) with an effect size of Cohen's $f = 0.11$. These analyses suggest that we would have had sufficient power to detect any critical interactions that had even a small effect size (with 0.10 being a "small" effect; Cohen, 1988). Although it will be important for further research to examine whether there are more subtle effects of age that could not be revealed here because of low power, we believe the present findings are an important, and necessary, first step.

We also feel confident that our older adults do not constitute an abnormally high-ability sample, which would raise concern that our null finding is because our older adults are particularly high-functioning. Comparing our older adults' cognitive task performance to their age-adjusted norms, we found our older adults to be above the age-adjusted norms for some tasks (Stroop interference and FAS verbal fluency; in the 80-89th percentile on these tasks), below average for the Digit Symbol task (an age-adjusted score of 7.85 with 10 being average), and at the population averages for both Digit Span and WCST (total categories achieved and number of errors made). We also compared our older adults' performance and demographics to other directed forgetting paradigms that tested older adults, and found that our older adults did not differ in age (although there is a trend for the older adults in our sample to be older than the others) or measures of cognitive ability for which the authors reported scores for those tasks (see Appendix B, supplementary material available online).

In conclusion, our studies demonstrate that there is no age-related deficit in the voluntary memory suppression of neutral or emotionally valenced information. Both older and younger adults show significantly lower recall for previously learned words that were suppressed from memory, and data from the independent-probe task reveals that this effect is because of the suppression of the target word and not simply because of a forgetting of the cue-target association. These findings suggest that the cognitive functions necessary to suppress information from memory are preserved in older adulthood. Additionally, the results reveal that emotional information can be suppressed from memory as readily as neutral information; despite age-related changes in other aspects of emotion processing (Kensinger & Leclerc, 2009; Mather & Carstensen, 2005; St. Jacques, Bessette-Symons, & Cabeza, 2009), aging does not impact the ability to suppress emotional memories.

[2] We thank an anonymous reviewer for offering this as a possibility.

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