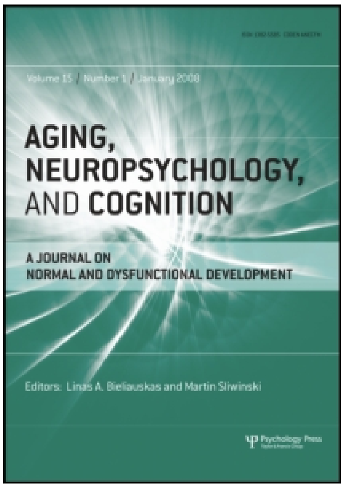

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Examining the Response Competition Hypothesis of Age Effects in Implicit Memory

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ABSTRACT

Age reductions in priming have been explained by differences in processing demands across implicit memory tests. According to one hypothesis, older adults show reduced priming relative to younger adults on implicit tests that require production of a response because these tests typically allow for response competition. In contrast, older adults do not show reductions in priming on identification tests that contain little response competition. The following experiments tested the specific role of response competition in mediating age effects in implicit memory. In Experiment 1, younger and older adults studied a list of words and were then given an implicit test of word stem completion. They studied a second list of words and were given an implicit test of general knowledge. Each implicit test contained items with unique solutions (the low response competition condition) and items with multiple solutions (the high response competition condition). In Experiment 2, younger and older adults were given explicit versions of the word stem completion and the general knowledge tests. Results showed an effect of age on explicit memory (Experiment 2), but no effect of age or response competition on priming (Experiment 1). Results are inconsistent with the theory that response competition leads to age effects on production tests of implicit memory.

Keywords: Implicit memory; Priming; Response competition; Age.

INTRODUCTION

A large body of research shows that older adults have worse memory performance than younger adults when memory is tested using explicit tests (see Light, 1996 for a review). The most notable feature of explicit tests, such as free recall, is that they require participants to intentionally (or explicitly)

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retrieve information from the past. In contrast, implicit memory tests are designed to measure the unintentional and unaware use of memory. On these tests, participants are presented with cues (e.g., *str*____) and asked to simply complete the cue with the first word that comes to mind. The typical finding is that, unbeknownst to participants, they are more likely to produce the target response (*strawberry*) if they had recently studied the item then if they had not studied it. This influence on performance is called priming, (Graf & Schacter, 1985; Tulving, Schacter, & Stark, 1982).

Studies comparing priming for younger and older adults are mixed. To account for the mixed pattern of implicit memory performance in older adults, several recent theories have been advanced (see Fleischman & Gabrieli, 1998; Light, Prull, La Voie, & Healy, 2000 for reviews). The majority of these theories posit that the inconsistent results are due to differences among implicit memory tests in terms of their processing demands. Variations in implicit memory tests are said to differentially affect older adults, because older adults are able to perform some cognitive processes, but not others. To anticipate, the current study tests the theory that age effects occur on implicit production tests that require participants to resolve response competition to demonstrate priming.

Identification and Production Priming Tests

One current test distinction offered to account for the effect of aging on implicit test performance is the distinction between tests that require production of a response and tests that require identification (or verification) of some specified property of an item (Gabrieli et al., 1999). The previously described word stem completion task can be classified as a production test. In this test, participants are given the initial three letters of a word and are told to complete the word stem with the first word that comes to mind. Thus, this test requires participants to produce an item. In contrast, other tests do not require production of a response, such as the perceptual identification test, which is considered an identification test because participants are simply required to identify a briefly presented word.

Several findings from implicit memory studies with older adults can be accommodated within the identification–production distinction. These studies show that older adults generally have reduced priming on production tests, but not on identification tests. For example, older adults often show reduced priming on the word stem completion test (Chiarello & Hoyer, 1988; Davis et al., 1990; Hultsch, Masson, & Small, 1991; Light & Singh, 1987; Winocur, Moscovitch, & Stuss, 1996; but see Clarys, Isingrini, & Haerty, 2000). However, older adults are generally not impaired on identification tests, such as the perceptual identification test (e.g., Light & Prull, 1995) or the word fragment completion test in which participants are given degraded versions of words and asked to quickly name these words (Light, Singh, & Capps, 1986; Rybash, 1996). A recent meta-analysis also supports the theoretical utility of classifying tests as identification versus production tests for understanding age effect in implicit memory (Light et al., 2000). This meta-analysis of several implicit memory studies showed that age effects were greater for tests that were *post-hoc* classified as production tests than those that were classified as identification tests. In addition, the distinction between identification and production tests gains additional support from implicit memory studies of older adults with Alzheimer's disease (AD) (Fleischman & Gabrieli, 1998; Gabrieli et al., 1994, 1999). The finding is that as compared with nondemented older adults, those with AD have reduced priming on production tests, but not on identification tests (Gabrieli et al., 1999). In addition, relative to younger adults, healthy (nondemented) older adults had worse production priming but similar identification priming performance.

The Role of Response Competition in Production Priming

It has been hypothesized that healthy older adults and those with AD may be impaired on production tests because these tests allow for response competition, whereas identification tests allow for less response competition (Gabrieli et al., 1999). For example, in production tests, such as the word stem completion test, participants are given a cue that can be correctly (or incorrectly) completed with multiple solutions. Thus, several different answers could be produced in response to the cue, *str__*, including *street*, *stripe*, and *strange*. The consequence would be that the primed word, *strawberry*, undergoes response competition from other nonstudied words and is less likely to be produced on this test compared to tests in which there is no competition. Identification tests, unlike most production tests, allow for less response competition because these tests provide information that guides retrieval, usually by re-presenting the actual target word at test and only requiring a response to that single item. For example, in the perceptual identification test, participants study the word, *strawberry*, and are later presented with a brief representation of the studied item, as well as several other nonstudied items, and are asked to read the word. Because the target word is presented at test, there is little opportunity for competition from other words.

Older adults are hypothesized to be particularly affected by the response competition inherent in production tests because older adults, and especially those with AD, have declines in attention abilities associated with frontal-lobe deterioration (Gabrieli et al., 1999; Vaidya et al., 1997; Vaidya, Gabrieli, Monti, Tinklenberg, & Yesavage, 1999). According to this account, declines in attentional abilities (see Craik & Jennings, 1992) limit many older adults from adequately encoding items at the time of study. Because production tests allow for multiple correct responses, it is then less likely that a studied item will be selected on these tests if the item was not encoded well originally (Gabrieli et al., 1999; Vaidya et al., 1997, 1999). A similar idea is that age-associated reductions in attentional control influence participants' ability to engage in nonconscious word selection at retrieval (Nyberg, Winocur, & Moscovitch, 1997; see also Winocur et al., 1996). The idea is that many competitors come to mind on the word stem completion task, and frontal abilities are needed to allow for the nonconscious preferential selection of the critical primed items and the complimentary inhibition of the nonstudied competitors. Regardless, both hypotheses suggest that age effects occur on production tests, such as word stem completion, because these tests allow for response competition.

Isolating the Role of Response Competition

Existing priming tasks do not allow one to directly examine the contribution of response competition on age effects in production priming because there are inherent confounds between currently used production and identification tests. Several test differences, aside from the response competition difference, could explain the reported age dissociation in priming on identification and production tests including differences in cue form (production tests do not present the entire studied item at test, while identification tests do), differences in dependent variables (the dependent measure for identification tests is typically reaction time, while the dependent measure for production tests is typically accuracy), and differences in potential susceptibility to contamination from explicit memory processes. Although implicit tests are assumed to measure unintentional uses of memory, these tests can become contaminated by explicit memory strategies (cf. Geraci & Rajaram, 2002). Because reaction time tests emphasize speeded responding, these tests may limit the opportunity to notice the study-test relationship and attempt to recollect the study episode. Tests with less of an emphasis on speed may allow for the use of these slow-acting explicit recollective memory strategies (MacLeod, 2008). This would mean that the age effects on production tests could be mediated by differences in the use of explicit memory strategies as opposed to differences in response competition (see Habib, Jelicic, & Craik, 1996; Light, 1991; Mitchell, 1995; Mitchell & Bruss, 2003; Russo & Parkin, 1993).

To isolate the role of response competition on age effects in implicit memory performance, the current study used implicit memory tests that differed only in the amount of response competition they allow, but not on the other three dimensions mentioned. We used two production tests, the word stem completion test (Experiment 1a) and the general knowledge test (Experiment 1b). We used the word stem completion test because age effects are frequently obtained using this test (Fleischman & Gabrieli, 1998; Light et al., 2000). We used the general knowledge test because this test is well-suited for manipulating response competition and for using unrelated study items. We also used the word stem completion and the general knowledge tests because these two tests differ according to another important processing distinction, the perceptual (word stem completion test) and conceptual (general knowledge test) distinction (see Roediger, Weldon, & Challis, 1989). Although this distinction does not appear to account for the entire pattern of age effects across tests, it is an important distinction in the younger adult literature that could interact in unforeseen ways with response competition (see Geraci, 2006; Jelicic, 1995; Jelicic, Craik, & Moscovitch, 1996; Rybash, 1996, for examples of age effects on conceptual, but not perceptual tests). For each test, we manipulated response competition by varying the number of possible responses to test items. Because we used two production tests, in neither case was the studied item presented in full at test. In addition, we used the same dependent measure (accuracy) across the high and low response competition conditions. Finally, given the potential problem of contamination, particularly for younger adults, the following studies were designed to limit the possibility of explicit memory contamination by using several of the procedures outlined in the literature (see Roediger & McDermott, 1993; Roediger & Geraci, 2003).

NORMING

One main goal of the current paper was to create new versions of two classic implicit memory tests in order to isolate the role of response competition. To this end we normed new sets of materials to ensure adequate baserate performance. For both the high and low response competition test conditions we created a pool of items that would not be too difficult or too easy for our participants to complete. The purpose of the norming studies was to determine how often participants respond to the test cue (e.g., *stra*___) using the target answer (e.g., *strawberry*) when they have not had recent prior exposure to the target answer (i.e., baserate performance). We normed our items to obtain a typical baserate performance of between 20 and 30%.

Participants

The word stems and general knowledge questions were normed on 60 younger adults (age 18–22) from Saint Peter's College. None of younger adults who participated in the norming study participated in the actual experiments presented later.

Materials

For the word stem completion task participants saw the first three letters of the target item. To examine the role of response competition, half of the word stems had a unique solution (e.g., *ber*__; target *berry*) these were considered the low response competition items. The other half of the word stems had multiple solutions (e.g., *she*__; target *sheet;* alternates, *shear, shell, etc.*) and were considered the high response competition items.

We used a pool of 120 five to nine letter medium to high frequency words (defined as higher than 10 based on Kucera & Francis, 1967, word frequency norms) to develop two study lists of 60 items (half with high response competition and half with low response competition). A word stem was defined as having high response competition if the word stem had three or more solutions in addition to the target item that also fell in the medium to high frequency range. Also, the target was chosen so that its average frequency was approximately equal to the average frequency of the alternates. We excluded targets (e.g., *drudge*) that had alternates that were all versions of the same word (e.g., *drunk*, *drank*, *drunkard*, *drinks*).

In addition to meeting the word frequency criteria, we used the norming data to examine output frequency. To be included in the pool of target items, all high response competition stems had to be completed during norming with at least five other words (the average number of alternate responses was 12). In addition, for each target the sum of the average probability of completing the stem with each alternate response had to exceed the probability of completing the stem with the target response. With these two measures (word frequency and output frequency) taken into consideration, the stems were considered to have multiple solutions that would cause high response competition for the target solution.

A word stem was defined as a low response competition item if there was only one possible medium to high frequency (defined as higher than 10 based on Kucera & Francis, 1967, word frequency norms) English word that could correctly complete the particular stem. In addition to the word frequency requirements, a stem was considered to have low response competition if the target word was also the most frequently used solution to that stem, with no other solution having more than a 15% probability of completion during norming. For both high and low response competition word stems, no proper nouns were used and all solutions were at least five letters long. Participants were told about these constraints before norming and experimental testing.

For the general knowledge test, two types of questions were used to examine the role of response competition. General knowledge questions were considered to have low response competition if they had only one possible correct solution (e.g., *What chemical element is needed to produce fire?*). High response competition general knowledge questions had multiple correct solutions (e.g., *What article of clothing do people wear to keep warm?*). A pool of 60 general knowledge questions was used to develop two study lists of 30 items, half low and half high response competition items. Questions were considered to have low response competition if there was only one correct answer and if, during norming, no other incorrect solution was used at an equal or higher probability than the correct solution. In other words, although these low response competition questions were factual questions with only one correct response participants still could have provided incorrect responses (for the question, *What chemical element is needed to produce fire?,* the correct answer is *oxygen,* but participants could have written incorrect responses, such as *hydrogen or nitrogen)*. To attempt to further reduce possible response competition (even from incorrect items), we only used low response competition questions that did not have alternate incorrect responses that were more likely to be used than the correct response. Questions were considered to have high response competition if there were at least three alternate correct answers (in addition to the target) and if the alternate correct answers were given during norming on average more often than the target answer. Because questions were chosen that had multiple correct answers, any answer from norming could be selected to serve as the target as long as it met the previous definition of having a probability that was lower than the average probability of the alternates. In other words, for the question, *What do people wear in the winter to keep warm?,* the correct target was *scarf,* but people could have written down *sweater, hat, jacket, boots,* etc. The correct target was chosen because it was less likely, on average, to be given as an answer than the alternates. All questions had one-word responses (e.g., *oxygen; scarf*). Some questions were taken from Blaxton (1989) and Hamilton and Rajaram (2001), and others were created specifically for this study.

Once we obtained a pool of items that met these criteria, we conducted a series of norming studies. For each norming study, participants were presented with separate booklets of word stems and general knowledge questions. Participants were instructed to complete the word stem or answer the question with the first word that came to mind as quickly as possible. For each item, we determined the mean percent of target responses used as a solution (i.e., baserate performance). We conducted norming studies until we obtained a final pool of items whose baserate completion was equal for both the low response competition items and the high response competition items. For the word stems, the baserate was 32% for the low response competition stems and 27% for the high response competition stems, $t(58) = 1.62$, $SE = 0.03$. For the general knowledge questions, the baserate was 28% for the low response competition questions and 27% for the high response competition questions, $t(58) < 1.00$.

GENERAL METHODS

Participants

Sixty-one younger adults (who did not participate in norming) and 39 older adults participated in the experiment to obtain 36 uncontaminated participants in each age group based on the responses to the post-test questionnaire. The average age for the 36 uncontaminated younger adults was 18.89 ($SD = 1.67$) and the average age for the 36 uncontaminated older adults was 74.78 ($SD = 6.64$). Younger adults were recruited from the Saint Peter’s

College psychology department's undergraduate participant pool and they received course credit for their participation. None of the participants had taken part in the previous norming studies. Older adults were recruited through the Washington University department's community participant pool and they received money for their participation.

All participants were given neuropsychological tests of FAS Verbal Fluency and Category Fluency Test (Spreen & Benton, 1977). The average FAS for younger adults (M = 40.31; SD = 14.41) was similar to the average FAS for older adults (M = 42.53; SD = 10.51; $F(1, 70) < 1$). Although the average Category Fluency was numerically greater for younger adults (M = 23.17; SD = 19.93) than older adults (M = 16.83; SD = 4.54), this difference did not reach significance; $F(1, 70) = 3.46$, MSE = 208.88, $p = .07$, possibly due to the large variability in performance for younger adults).Younger and older adults were also given the Shipley Vocabulary Test (Zachary, 1986) to assess word knowledge. Older adults had higher vocabulary scores (M = 34.08, SD = 4.51) than younger adults (M = 26.56, SD = 3.54), $F(1, 70) = 61.91$, MSE = 16.44. Education level was higher for older (M = 15.83, SD = 2.51) adults as compared to younger (M = 12.11, SD = 0.67) adults, $F(1, 70) = 73.80$, MSE = 3.38. Older adults were also given a Mini-Mental State Exam (MMSE; Folstein, Folstein, & McHugh, 1975) to exclude from the analyses people with significant impairments in cognitive functioning. The average MMSE was 28.19 (SD = 1.26), and no one in the sample scored lower than 25 on this test. Lastly, all participants filled out a demographic questionnaire that included several health questions. None of the younger or older adults included in this sample reported any history of stroke, other neurological disorder, brain injury, or serious cardiovascular conditions.

Design

Both experiments used a 2 × 2 mixed-subjects design, with participant group (younger and older) serving as the between subjects variable and response competition (high response competition and low response competition) serving as the within-subjects variable. The following experiments (1a and 1b) were run in the same experimental session, and the order of the studies was counterbalanced. Because the experiments occurred in the same session, no words were repeated across the two sets of materials.

EXPERIMENT 1A: WORD STEM COMPLETION

Materials

The 120 words corresponding to the previously normed word stems were separated into two word lists (List A and List B) consisting of 60 word stems; 30 with low response competition and 30 with high response competition solutions. Independent measures t-tests showed that these lists did not differ on baserate performance (List A = 30% and List B = 29%, $t(58) < 1.00$), number of letters in the completed words (List A = 5.87 and List B = 6.40, $t(58) = 1.77$, $SE = 0.30$), or word frequency (List A = 111.33 and List B = 89.55, $t(58) < 1.00$. These lists were used to counterbalance study status across participants. Half of the participants were presented with List A during the study phase and the other half were presented with List B. At test participants received 180 word stems presented in a random order (60 studied, 60 nonstudied, and 60 filler items). Filler items were not analyzed, but were included to decrease the proportion of studied items in the test list. Because explicit contamination is an important issue for interpreting age effects in priming, we attempted to limit explicit memory contamination by constructing the test list such that studied items made up only 33% of the test items. With this test list construction, participants may be less likely to notice the studied items and engage in explicit attempts at retrieval (Roediger & McDermott, 1993; Roediger & Geraci, 2003).

Procedure

Participants studied 60 medium frequency words, plus four filler items at the beginning and end of the list to avoid primacy and recency effects. The studied words were presented in a fixed random order. Each word was presented on the computer screen for 3 s using Superlab Version 2.0 (Cedrus Corporation, 1999) experimental software. Participants were told to try to remember the words for a free recall task that they would eventually receive. After the study session ended, participants were told that they would have to wait to take the free recall test because we were interested in longer-term memory performance. In the meantime, they were told they would engage in several short unrelated reaction time tasks while they awaited the free recall test. In fact, the implicit word stem completion test itself served as one of the unrelated reaction time tasks. Before taking the word stem completion task they were given a 5-min perceptual task in which they had to rank order various interior angles from smallest to largest. This task was taken from a Dental Admissions Exam practice booklet. They were then given the implicit word stem completion test. As part of the cover story, participants were told that the purpose of the word stem completion task was to measure their reaction time to solving the stems while they awaited the free recall test.

Participants were given a packet with several three-letter word stems (e.g., *app_*) and were told to work as quickly as possible. They were told not to use proper nouns, that all the solutions were at least five letters long, and that there were no correct answers. Participants were encouraged to complete the word stems as quickly as possible and that they should skip any items that they could not complete within approximately 10 s. The test included stems that corresponded to 30 words from the study list, plus stems corresponding to 30 new words, and 30 filler words. Unbeknownst to the participants half the studied and nonstudied items had high response competition solutions while half had low response competition solutions. Two test versions were created to counterbalance for study status (which list items were studied versus nonstudied). We used two fixed random orders for each test list. This test took approximately 10 min, including instructions.

Immediately after participants finished the word stem completion test, they were given the anticipated free recall test. Participants were given a maximum of 5 min to complete the test. Participants then took a short break, filled out a demographic questionnaire, took the vocabulary test, and older adults took the Mini-mental State Exam. Participants were then reminded that they would now have to repeat the procedure with a different set of words. They were told to forget about the words they had seen in the previous experiment, and that they would now be essentially participating in another, separate, memory experiment. Again, they were told that they would study a list of words, take some unrelated reaction time tests, and then take the free recall test.

EXPERIMENT 1B: GENERAL KNOWLEDGE

Materials and Procedure

A pool of 60 general knowledge questions was used to develop two lists of 30 items, List A and List B (half high response competition and half low competition solution). Independent measures *t*-tests showed that these lists did not differ on baserate performance (List A = 27% and List B = 27%, $t(28) < 1.00$). Word frequency information was not available for many of the general knowledge solutions so this characteristic was not analyzed.

Participants studied 30 words presented in a fixed random order, plus 4 items at the beginning and end of the list. Each word was presented for 3 s and again participants were told to try to memorize the words for the eventual free recall test.

Before taking the general knowledge test, participants were again given a 5-min perceptual task taken from a Dental Admission Practice booklet, but this time they had to mentally rotate three-dimensional objects to decide which picture of a cutout hole the object would fit. Immediately following the study session, participants were given the implicit general knowledge test (disguised as a distracter task). The implicit test consisted of 90 general knowledge questions. Of these questions, 30 could be answered with studied items, 30 with nonstudied answers, and 30 served as filler items. Half of the studied and nonstudied questions had been determined to be high response competition items, while the other half were low response competition items.

Participants were given a packet containing the general knowledge questions and were told that the purpose of this task was to fill the delay before the free recall test. They were told that they were helping us gather materials for a future experiment designed to examine what people of different ages know about various topics. Participants were told to work fairly quickly and to guess if they were not sure of an answer. They were told that some questions had several correct answers, and that they should write the first answer that comes to mind. Including instructions, this test took approximately 15 min to complete. Two versions of this test were created to counterbalance for study status (which items were studied versus nonstudied). We used two different fixed orders for each version.

After the general knowledge test, participants were given the anticipated free recall task for this set of study words. Participants were warned that they should only try to recall the second set of words they studied during the experiment. Finally, participants were given a post-test questionnaire to assess possible awareness on either the word stem completion task or the general knowledge task. Participants were asked open-ended questions regarding strategies they used to complete each task. They were given the following four questions.

Question 1 (filler question): 'This question refers to the 2 lists of words you were instructed to memorize. Please list any strategies that you used to memorize these words'.

Question 2: 'This question refers to language test you took to help us prepare materials for an up-coming experiment. Recall that you were given the first three letter of a word, gir___, and were told to complete it with a word that fits, such as *giraffe*. Please list any strategies you used to perform this task'.

Question 3 (filler question): 'This question refers to the perceptual experiment you participated in. Please list anything you think might have helped you recall certain presidents'.

Question 4: 'Lastly, this question refers to the general knowledge questions you answered. Again, please list any factors that you think might have influenced your ability to answer these questions correctly'.

If participants mentioned the study list in response to the awareness questions for either task, they were counted as test-aware and their data were not included in the initial analyses.

RESULTS

The level of significance was set at .05 for all analyses. Because of procedural and response differences, data from the word stem completion test and the general knowledge test were analyzed separately.

Experiment 1a: Word Stem Completion

Table 1 shows younger and older adults' performance on the implicit word stem completion test. Means for the proportion of word stems correctly completed for studied and nonstudied solutions, as well as the resulting priming difference, are presented in Table 1. The dependent measure was priming, which is obtained by subtracting the proportion of correct target responses to test items with nonstudied solutions from proportion of correct target responses to test items with studied solutions. Using paired *t*-tests, results showed that word stem completion priming was significant for both younger, $t(36) = 9.05$, $SE = 0.02$, and older adults, $t(36) = 6.14$, $SE = 0.02$. These priming scores were then used in a 2 × 2 ANOVA to examine the effects of age (younger vs. older) and response competition (high vs. low response competition) on priming. Results showed that there were no main effects of age or response competition and no interaction between the two variables (all F values < 1).[1] Thus, in contrast to the predictions of the response competition theory, older adults did not show greater reductions in priming relative to younger adults in the high response competition condition than the low response competition condition.

A closer look at the data reveal small baseline differences for the groups that can qualify the conclusions made using absolute priming scores. Therefore we examined priming scores using a proportion, where the percent increase in priming was divided by the remaining amount possible for priming to increase given the existing base rate (priming/1-nonstudied base rate). Results using the proportional priming scores showed the same pattern as the absolute priming: No main effects and no interaction (all F values < 1).

TABLE 1. Implicit word stem completion test performance showing the proportion correct for studied and nonstudied targets, and priming scores for younger and older adults

	Response competition			
	Low		High	
	Younger	Older	Younger	Older
Studied	.60 (.19)	.53 (.18)	.48 (.13)	.49 (.15)
Nonstudied	.42 (.15)	.38 (.20)	.29 (.12)	.35 (.14)
Priming	.18 (.16)	.16 (.16)	.18 (.16)	.15 (.21)

*Note: SD*s are in parentheses.

[1]Note that when subsamples of younger and older adults are matched on vocabulary and education level, the priming results for these groups do not change for either condition of the word stem completion test. To anticipate, the priming results for the general knowledge test are also identical using matched subsamples.

The previous analyses contained only participants who did not indicate any awareness of the study-test connection. Under these conditions, there was no effect of age or response competition on priming. However, it is possible that age effects do sometimes occur in high response competition conditions because younger adults are using explicit memory strategies to retrieve the target item. One might assume that using explicit memory strategies to recall would increase the likelihood that participants would select the target item, particularly in the face of multiple possible responses.

Examination of the post-test questionnaires showed that several younger adults ($N = 25$) mentioned the study list as a factor contributing to their task performance on the implicit tests, while only three of the older adults mentioned the study list in connection to their performance on the implicit tests. It is notable that so few older adults reported awareness. This finding could be taken to mean that older adults are simply less test aware, consistent with a deficit in explicit memory processes, or that the use of post-test questionnaires is problematic with older adults, who may not be able to accurately recall their true levels of awareness from the time of testing (see Geraci & Barnhardt, 2008, unpublished manuscript[2]). In any case, because there were so few aware older adults, we did not examine the contribution of awareness to priming for older adults.

Because there were larger numbers of aware younger adults, we statistically compared performance for aware and unaware groups. Because awareness was assessed using post-test questionnaires, we did not have equal numbers of aware and unaware younger adults or counterbalanced groups. Therefore, we first examined the effect of test version on priming to determine if these groups of aware and unaware younger adults could be compared. Results showed that there was no effect of test version on word stem completion priming for younger adults, $t(29) < 1$, so the contribution of awareness to priming was examined. Results showed that word stem priming did not differ for aware ($M = 0.20$; $SD = 0.18$) and unaware younger adults ($M = 0.18$, $SD = 0.12$), $t(59) < 1$. Thus, the relationship between awareness and priming is somewhat inconclusive. The role of explicit memory influences on age effects in priming awaits more systematic investigation.

Regardless, the important point is that when we examined unaware younger and older adults, there was no effect of age or response competition on priming.

[2]Geraci, L., & Barnhardt, T. (2008). Can older adults accurately report test awareness on priming tasks: Comparing on-line and post-test reports of awareness in younger and older adults. *Unpublished manuscript.*

Experiment 1b: General Knowledge

Table 2 shows the mean proportion of general knowledge questions completed with studied and nonstudied exemplars, and the resulting difference, for the implicit general knowledge test conditions. Both younger, $t(36) = 3.35$, $SE = 0.02$, and older adults, $t(36) = 3.19$, $SE = 0.01$, were more likely to correctly answer general knowledge questions with target studied items when they had studied the answers than when they had not (again showing significant levels of priming for both age groups).

Turning to the main question of interest: did older adults show reduced priming relative to younger adults under conditions of high, but not low, response competition? Results from the 2 × 2 ANOVA were similar to the word stem completion results: there were no main effects and no interaction between age and response competition condition, all F values $(1, 79) < 1$. Thus, again results showed that the presence of response competition did not produce an age effect in priming. Results showed the same pattern using proportional data and are therefore not reported.

As with the word stem completion results, we examined whether there might be an effect of test awareness on priming for high response competition conditions resulting from younger adults' selective use of explicit memory strategies. Again, because there were only three test aware older adults, we did not examine the influence of awareness on priming for this group. Because of the larger number of aware younger adults, we analyzed the effect of awareness on priming for younger adults. There was no effect of test version on general knowledge priming for younger adults, $t(29) < 1.59$, $SE = 0.03$, so the contribution of awareness to priming was examined. Following the word stem completion priming pattern of data, there was no difference in general knowledge priming for aware ($M = 0.12$, $SD = 0.11$) and unaware ($M = 0.08$, $SD = 0.14$) younger adults, $t(59) = 1.18$, $SE = 0.05$, however in this test the data were in the predicted direction suggesting that

TABLE 2. Implicit general knowledge test performance showing the proportion correct for studied and nonstudied targets, and priming scores for younger and older adults

	Response competition			
	Low		High	
	Younger	Older	Younger	Older
Studied	.33 (.15)	.37 (.16)	.33 (.13)	.28 (.10)
Nonstudied	.23 (.15)	.32 (.16)	.27 (.13)	.22 (.12)
Priming	.10 (.16)	.05 (.16)	.06 (.18)	.06 (.14)

*Note: SD*s are in parentheses.

awareness may mediate age effects under conditions of high contamination on certain tests. Again, for present purposes, the important finding is that when younger and older adults are test unaware, there is no effect of age or response competition on priming.

Free Recall

The free recall data are presented in Table 3. As expected, younger adults showed better recall performance than older adults on both the free recall test that followed the word stem completion test, $F(1, 70) = 212.97$, $MSE = 0.03$, and the free recall test that followed the general knowledge test, $F(1, 70) = 196.61$, $MSE = 0.03$. For both free recall tests there was no effect of having been previously tested on a multiple or unique solution implicit test (there was no main effect of response competition) and there was no interaction between age and response competition (all F values < 1).

Neuropsychological Test Results

Age declines in priming on tests with response competition have been attributed to reduced frontal functioning in older adults. The test of verbal fluency, or FAS (Spreen & Benton, 1977), is considered to measure processes associated with frontal functioning, such as perseveration, and in the aging and implicit memory literature FAS has often been used as an indicator of frontal functioning and shown to correlate with some forms of priming, including word stem completion (e.g., Davis et al., 1990; Nyberg et al., 1997; Winocur et al., 1996) and category production (Geraci, 2006). We predicted that FAS would correlate with free recall performance because both tests require effortful controlled processes often associated with frontal lobe functioning. The question was whether FAS scores would also correlate with priming under conditions of response competition because these same effortful controlled processes would be necessary to resolve response competition.

To explore this hypothesis, we examined the correlation between FAS scores and priming on the word stem completion and the general knowledge

TABLE 3. Experiments 1a and 1b final free recall performance for younger and older adults

	Response competition			
	Low		High	
	Younger	Older	Younger	Older
Experiment 1a	.18 (.09)	.14 (.11)	.18 (.11)	.14 (.12)
Experiment 1b	.20 (.13)	.19 (.14)	.20 (.10)	.18 (.17)

*Note: SD*s are in parentheses. Free recall performance is from participants who were classified as unaware (N = 36 for younger and older adults) on the implicit test.

tests for both the response competition conditions. For older adults, contrary to expectations, results showed no correlation between FAS performance and word stem completion priming for the low response competition condition (r = –.13) and the high response competition condition (r = .02). In addition, there was no correlation between FAS performance and general knowledge priming under low (r = .01) or high (r = .00) response competition conditions. As expected, FAS performance did correlate with explicit memory performance as measured by average free recall performance across both tests, r = .21. For younger adults, the correlation between FAS performance and word stem completion priming was positive, but not significant, for both the low (r = .15) and high response competition conditions (r = .12). Similarly for the younger adults the correlation between FAS performance and general knowledge priming was positive, but not significant, for both the low (r = .32) and high response competition conditions (r = .29). As with the older adults, younger adults' free recall performance was significantly correlated with FAS performance across both tests, r = .33. Thus, FAS was correlated with explicit, but not implicit memory performance and we did not find larger correlations with FAS and priming in the high response competition condition relative to the low response competition condition for younger or older adults.

The correlation between FAS performance and priming for older adults was approximately zero in all conditions except one (the low response competition condition of word stem completion where the correlation was –.13). Here, the negative correlation is small and nonsignificant, but nonetheless unexpected. To speculate, it could be that older adults with high FAS performance may have also had larger vocabularies and thus higher baseline performance on low response competition stems. To examine this possibility, we examined the correlation between FAS and nonstudied and studied low response competition items separately. This analysis showed a similar positive (albeit nonsignificant) correlation between FAS and studied items (r = .21) and nonstudied items (r = .29). Similarly, for the high response competition condition, FAS is positively (but not significantly) correlated with studied (r = .26) and nonstudied items (r = .26). Thus, it appears that FAS performance is simply correlated with solving word stems, regardless of whether they have studied or nonstudied solutions, and regardless of whether they have unique or multiple solutions. This finding makes sense given the high similarity between the FAS task and the word stem completion task. Indeed, the correlations between FAS and general knowledge performance is less consistent (for low response competition, the correlation with studied is .39 and nonstudied is .27; for high response competition, the correlation with studied is –.05 and nonstudied is –.03). In the low response competition condition, FAS performance may be generally correlated with correct responses to low response competition items (factual questions with single correct answers) because people with better vocabularies can perform better on FAS and these people may know more general knowledge facts. In support of this hypothesis, results from this analysis showed that FAS was significantly correlated with vocabulary (r = .43).

Taken together, these results show that while explicit memory performance was affected by age and frontal functioning (as measured by the FAS test), priming was unaffected by both. Importantly for present purposes, neither age nor frontal functioning differentially influenced priming under high response competition conditions relative to low response competition conditions. Thus, these results do not support the response competition theory of age effects in priming. Results suggest that processes associated with frontal lobe functioning as measured by FAS are not necessary to show priming under conditions of response competition, at least as response competition is defined in the current study (see also Geraci, 2006). This interpretation is consistent with the finding of a lack of an age effect under conditions of response competition.

EXPERIMENT 2: EXPLICIT WORD STEM CUED RECALL AND GENERAL KNOWLEDGE

Results from Experiment 1 showed no age effect in priming across two different implicit tests (word stem completion and general knowledge) even under conditions of high response competition. However, because these were newly created versions of standard tests, it is possible that our materials were unusual and do not demonstrate age effects of any kind. Experiment 2 was designed to examine whether we could obtain an age effect in explicit memory using the materials from Experiment 1. Finding an age effect with explicit instructions would indicate that the results obtained in Experiment 1 were due to the implicit nature of the tests. Further, this result would demonstrate an age effect in explicit memory when the explicit test was not contaminated by prior implicit testing, as was the case for the free recall results in Experiment 1.

GENERAL METHODS

Participants

Twenty-four younger adults and 24 older adults (average age = 76.96, SD = 8.96) participated in the experiment. Younger adults (average age = 18.79, SD = 1.10) were recruited from the St. Peter's College psychology department's undergraduate participant pool and they received course credit for their participation. Older adults were recruited through the Washington University department's community participant pool and they received money for their participation. None of the participants took part in the previous experiments or norming sessions. Two older adults were excluded from the following analyses for computer difficulties and for not following instructions on the explicit tests.

Younger and older adult participants were given the Shipley Vocabulary Test (Zachary, 1986) to assess word knowledge. Older adults had higher vocabulary scores (M = 34.82, SD = 2.99) than younger adults (M = 26.73, SD = 3.46), $F(1, 44) = 71.49$, $MSE = 10.51$. Education level was slightly higher for older (M = 14.82, SD = 3.23) adults than younger adults (M = 13.58, SD = 0.83) adults, although this difference was not significant, $F(1, 44) = 3.28$, $MSE = 5.34$. Lastly, all participants filled out a demographic questionnaire that included several health questions. None of the younger or older adults included in this sample reported any history of stroke, other neurological disorder, brain injury, or serious cardiovascular conditions.

Design

Both experiments used a 2 × 2 mixed-subjects design, with participant group (younger and older) serving as the between subjects variable and response competition (high response competition and low response competition) serving as the within-subjects variables. Experiments 2a (word stem cued recall) and 2b (explicit general knowledge) were run in the same experimental session, and the order of the studies was counterbalanced. Because the experiments occurred in the same session, no words were repeated across the two sets of materials.

Materials

The materials were identical to those used in Experiment 1, with the exception that there was no post-test questionnaire or final free recall test.

Procedure

The procedure was identical to that used in Experiment 1 with the exception that participants were simply told during study that they were to take an unspecified memory test (rather than a free recall test) for the words. For these tests, they were given the word stem and general knowledge tests with explicit retrieval instructions. Participants were instructed to complete word stems and to answer general knowledge questions only with words that they had studied in the respective study sessions. If they could not answer the stem or question with a studied word they were instructed to leave the cue blank. Unlike Experiment 1, participants did not complete a post-test questionnaire and they did not take a final free recall task.

RESULTS

The level of significance was set at .05 for all analyses. Because of procedural and response differences, data from the explicit word stem cued recall test and the explicit general knowledge test were analyzed separately.

Experiment 2a: Word Stem Cued Recall

Table 4 shows younger and older adults' performance on the explicit version of the word stem completion test. We examined the effect of age and response competition on memory accuracy (accuracy scores were derived by subtracting false alarms from correct recall). As expected, results showed that there was a main effect of age, showing that younger adults had better explicit memory performance than older adults, $F(1, 44) = 9.29$, $MSE = 0.10$. Higher accuracy for younger adults than older adults was due to the fact that older adults were more likely to falsely recall nonstudied items than were younger adults, consistent with much of the aging and false memory literature (e.g., Balota et al., 1999; Norman & Schacter, 1997; Roediger & Geraci, 2007), perhaps due to source monitoring difficulties (e.g., Ferguson, Hashtroudi, & Johnson, 1992) or an accessibility bias in which they base responding on familiarity (e.g., Jacoby, 1999). There was no effect of response competition, $F < 1.00$, and no interaction between age and response competition on explicit memory performance, $F(1, 44) = 1.28$, $MSE = 0.03$. Thus, we obtained the expected age effect in explicit memory using our new materials.

Experiment 2b: Explicit General Knowledge

Table 5 shows the mean proportion of general knowledge questions completed for studied exemplars and the false alarm rate for the non studied questions for both the low response competition items and the high response

TABLE 4. Experiment 2a explicit word stem cued recall test performance showing the proportion correct for studied and nonstudied targets, and difference scores for younger and older adults

	Response competition			
	Low		High	
	Younger	Older	Younger	Older
Studied	.51 (.17)	.55 (.16)	.48 (.16)	.42 (.20)
Nonstudied	.09 (.13)	.29 (.28)	.02 (.04)	.20 (.12)
Difference	.43 (.21)	.26 (.29)	.46 (.16)	.23 (.34)

*Note: SD*s are in parentheses.

TABLE 5. Experiment 2b explicit general knowledge cued recall test performance showing the proportion correct for studied and nonstudied targets, and difference scores for younger and older adults

	Response competition			
	Low		High	
	Younger	Older	Younger	Older
Studied	.31 (.19)	.33 (.19)	.37 (.16)	.28 (.18)
Nonstudied	.02 (.04)	.03 (.04)	.02 (.04)	.03 (.06)
Difference	.29 (.19)	.30 (.20)	.35 (.16)	.25 (.18)

*Note: SD*s are in parentheses.

competition items. As with the word stem cued recall test, we examined the effect of age and response competition on memory accuracy (accuracy scores were derived by subtracting false alarms from correct recall). There was no effect of age, $F(1, 44) = 1.02$, $MSE = 0.05$, or response competition, $F < 1.00$ on explicit general knowledge performance. However, there was a significant interaction between age and response competition, $F\ (1, 44) = 4.93$, $MSE = 0.01$, showing an age effect for general knowledge questions with high response competition but not general knowledge questions with low response competition. Although not predicted, the lack of an age effect in the low response competition condition may have occurred because older adults knew more of the answers to the general knowledge questions than younger adults. Support for this idea comes from the nonstudied baserate performance reported in Experiment 1b. When there was only one correct answer to the general knowledge questions (low response competition condition), older adults were much more likely to answer these questions correctly than were younger adults when they had not studied the answers (baserates for older adults in Experiment 1b = 0.32; $SD = 16$, and younger adults = 0.23; $SD = 0.15$). In contrast, baserates in the implicit general knowledge test did not differ significantly for younger and older adults for the questions with multiple correct answers (younger = 0.27; $SD = 0.13$ and older = 0.22; $SD = 0.12$).

GENERAL DISCUSSION

The present experiments were designed to test the theory that older adults' priming performance on production tests of implicit memory is mediated by response competition (Fleischman & Gabrieli, 1998; Gabrieli et al., 1999). We tested this hypothesis using two production priming tests that included items with high response competition (items with multiple responses) and items with low response competition (items with unique responses). According to the response competition hypothesis, older adults should show greater reductions in priming relative to younger adults under conditions of high response competition, but not under conditions of low response competition. Results from two classic implicit production tests (word stem completion and general knowledge), failed to support this hypothesis. Instead, results showed equivalent priming for younger and older adults across both the high and low response competition test conditions. In contrast to the implicit test results, older adults showed worse explicit memory performance on a final free recall test (Experiment 1) and on the explicit versions of word stem completion and general knowledge tests (Experiment 2) compared to younger adults. Thus, results showed an effect of age on explicit memory performance, but not implicit memory performance, even under conditions of high response competition.

The production-identification distinction has been a popular explanation for the inconsistent age effects in implicit memory. Age differences in priming are said to appear on tests that require the production of a response and not on tests that require the identification or verification of a response (Gabrieli et al., 1999). The assumption has been that age effects occur on production tests because these tests allow for response competition, while identification tests do not (or they allow for less response competition). To the best of our knowledge, the current study provides the first direct test of this theory.

While the current study does not support the hypothesis that age effects occur on implicit tests that contain response competition, as mentioned earlier there are several other test differences aside from the response competition difference that could explain the reported age dissociations in priming on identification and production tests. Most obviously, these tests differ in whether they require production of a response or not. This aspect of the testing situation has been shown not to explain age effects in priming (Prull, 2004). However, as mentioned earlier, identification and production tests also differ in whether they: (1) present the intact studied item during testing, (2) measure speeded responding or accuracy, and (3) allow for the use of explicit memory strategies. In the current study, these variables were all held constant across conditions and only response competition was varied. Using this design produced equivalent priming for younger and older adults. It is possible that the critical processing distinction between production and identification tests lies along one of these other processing differences. For example, older adults may show reduced priming relative to younger adults on tests that do not contain cues that re-present that studied target. In addition, older adults may show reduced priming relative to younger adults on tests that do not require highly speeded responding. Future research will be needed to systematically examine the contribution of each of these test factors in producing age effects in priming.

Tests that do not place demands on speeded responding may be more likely to show age effects in priming compared to speeded tests because tests that allow for relatively long response times may afford younger adults the opportunity to become test aware and to augment their performance using explicit memory strategies. As previously mentioned the problem of contamination is a serious one for age comparisons because older adults have impaired explicit memory as compared to younger adults. Thus, it makes sense that younger adults' implicit performance is more likely to be contaminated by explicit memory strategies than older adults' implicit memory performance, making it possible for so-called age effects in implicit memory performance to be influenced by younger adults' differential use of explicit strategies. Indeed, recent work shows that, using conditions that promote test awareness, younger adults show more awareness and more priming than older adults on production tests of implicit memory. Further, levels of awareness in both groups are directly related to their levels of priming (Geraci & Barnhardt, 2008, unpublished manuscript). However, when the opportunity for awareness was reduced, there were no age differences in reports of awareness or in levels of priming. Thus, the results from the Geraci and Barnhardt study suggest that test awareness may contribute to age effects in priming under certain conditions. In the current study, we went to great lengths to reduce the opportunity for such awareness, and this factor may contribute to the lack of an age effect.

While we have proposed that explicit contamination or other various test distinctions may explain the presence of age effects in implicit memory, it is still possible that response competition is the key to understanding age effects in repetition priming. In fact it could be that some other source of response competition is critical for understanding age effects in priming. In the current study, response competition was manipulated using a very straightforward method: the number of possible responses was varied across test conditions. However, there are typically many other potential sources of response competition in a standard production priming test. For example, in a word stem completion test, there is the potential for response competition not only because there is more than one correct alternative stem solution, but also because some of the alternatives may come to mind with a higher probability than the target response. This situation could occur if the target item is a particularly low frequency item, for example. Indeed, there is evidence that age effects in priming occur for low frequency target items, but not high frequency items (Ryan, Ostergaard, Norton, & Johnson, 2001). Additional work will be needed to examine the potential role of other sources of response competition.

Finally, it may be that the previously reported age effects in production priming are the result of inclusion of heterogeneous groups of older adults or those with early stage AD. Although the current study did not find evidence for an influence of older adults' neuropsychological performance on high and low response competition priming, it is possible that other individual differences, including AD, impair priming under conditions of response competition. For now, though, the current studies suggest that response competition does not explain normal aging effects in implicit memory. Instead, other processing distinctions may be important to consider, or it may be the case that priming is intact in healthy aging.

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