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A Test of the Frontal Lobe Functioning Hypothesis of Age Deficits in Production Priming

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Older adults have been hypothesized to show reduced priming relative to younger adults on implicit memory tests that require production of a response because these tasks place high demands on attentional processes associated with frontal lobe function, which are often reduced with age (see D. A. Fleischman & J. D. E. Gabrieli, 1998). The current study directly tested this frontal lobe hypothesis of age effects in production priming. Younger adults and older adults who differed in their attentional abilities as measured by a battery of neuropsychological tests were given two production priming tasks, word stem completion and category production, followed by explicit free recall tests. Results showed that explicit memory performance was reduced by age and older adults' frontal functioning. Age and frontal functioning influenced category production priming but not word stem completion priming. Results failed to support the frontal account of age reductions in production priming. Instead, results implicate the influence of other processes often involved in production priming tasks, such as explicit memory strategies and response competition, as critical for understanding age effects in implicit memory performance.

Keywords: aging, implicit memory, priming, identification–production tests

Much research shows that older adults have worse memory performance than younger adults (see Light, 1996, for a review). This conclusion is generally true when memory is measured with explicit tests that require participants to intentionally (or explicitly) attempt to remember past events. However, the extent to which aging affects performance on another class of tests, called implicit memory tests, is less well understood. Unlike explicit tests such as free recall, implicit tests are designed to measure the automatic and unaware use of memory. Research on implicit memory and aging is inconclusive: Some studies demonstrate that implicit memory performance is reduced with age, whereas other studies demonstrate that it is unaffected by age (see Fleischman & Gabrieli, 1998; La Voie & Light, 1994; Light, Prull, La Voie, & Healy, 2000, for reviews).

Several theories have been advanced to account for the mixed pattern of implicit memory performance in older adults. The majority of these theories posit that the inconsistent results occur because implicit memory tests differ in their processing demands, only some of which are affected by aging. There are two main processing distinctions that have been proposed in the implicit memory literature: the perceptual–conceptual test distinction and the identification–production test distinction.

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Perceptual and Conceptual Tests

A critical distinction exists between tests that are primarily influenced by perceptual processing (called *perceptual tests*) and those that are primarily influenced by processing meaning (called *conceptual tests*; Blaxton, 1989; Roediger, Weldon, & Challis, 1989). Indeed, the majority of the work with younger adults demonstrates the utility of this test distinction (see Roediger & McDermott, 1993, for review). Take for example the popular word stem completion test. In this test, participants are given a series of word stems (e.g., *str*___) and are asked to complete them with the first word that comes to mind. This test is considered to be a perceptual test because performance on this test is largely affected by processing of the stimuli's physical features (e.g., its modality of presentation). By contrast, participants could be given a cue (*Types of Fruit*) and asked to list examples of this category (e.g., "strawberry," "apple," "banana," "cherry," etc.). This type of implicit test is referred to as a conceptual test because performance on this test is largely affected by analysis of the stimuli's meaning (e.g., its category membership) and not by its surface characteristics (e.g., its modality of presentation). In both cases, unbeknownst to participants, the test can be accomplished using previously studied items. Indeed, the typical finding is that participants are more likely to produce the item *strawberry* if they studied the item than if they had not studied it. The influence that studied items have on performance (either on accuracy or reaction time) is termed priming (see Roediger & McDermott, 1993; Tulving & Schacter, 1990).

The perceptual–conceptual distinction has proved useful in accounting for much of the data with younger adults, and some researchers have applied this distinction to explain age effects in implicit memory performance (e.g., Jelicic, 1995; Jelicic, Craik, & Moscovitch, 1996; Rybash, 1996). The hypothesis is that older adults have intact perceptual priming but reduced conceptual priming. However, this conceptual deficit hypothesis cannot account for the various patterns of age effects across implicit memory tests. Although some studies do demonstrate age equivalence in perceptual priming, others studies show that as compared with younger adults, older adults often have reductions in priming on the perceptual test of word stem completion just described (Chiarello & Hoyer, 1988; Davis et al., 1990; Fleischman et al., 1999; Hultsch, Masson, & Small, 1991; Light & Singh, 1987; Winocur, Moscovitch, & Stuss, 1996). Similarly, whereas older adults show reductions on some conceptual tests, they also show similar levels of priming as younger adults on other conceptual tests, including the test of category verification, in which participants are given categories and are asked to quickly indicate whether target items are members of the category (speeded responding on this task to studied items as compared to nonstudied items is evidence of priming; e.g., Light, Prull, & Kennison, 2000; Small, Hultsch, & Masson, 1995). Taken together, these results suggest that it is not simply conceptual priming that is reduced with age.

Production and Identification Tests

A different look at this literature reveals another potentially important 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., 1994; Gabrieli et al., 1999; Vaidya et al., 1997). Take for example the category production and the category verification tests. As described earlier, in the category production test, participants study a list of items, such as the word *strawberry*, and are later given the ostensibly unrelated task of quickly listing instances of fruits. In the category verification test, again participants study a list of items such as *strawberry*, but at test they are simply asked to indicate quickly whether the item is a type of fruit. Both tests require conceptual, or category, knowledge, but they have different processing demands: The category production test requires participants to produce category exemplars, whereas the category verification test simply requires participants to identify an item as belonging to a given category. The identification–production test distinction crosses the broad distinction between perceptual and conceptual processes. Both the perceptual test of word stem completion and the conceptual test of category production require production, whereas both the perceptual identification and the category verification task require identification.

The focus on different processing demands among conceptual and perceptual tests parallels recent research on implicit memory in younger adults. The work with younger adults demonstrates that performance on both perceptual and conceptual tests can be dissociated by the specific processing demands within each type of test. For example, several studies have shown that performance on conceptual tests depends on the exact type of conceptual processing required by the test, not simply on the conceptual nature of the test (e.g., Cabeza, 1994; Geraci & Rajaram, 2004; Hamilton & Geraci, 2006; Mulligan, 2002; Vaidya & Gabrieli, 2000; Vaidya et al., 1997; Weldon & Coyote, 1996). For example, Geraci and Rajaram (2004) showed that the isolation effect (superior memory for isolated items, such as the item *banana* printed in a list of vehicles) was obtained on the implicit conceptual test of category verification test but not on the implicit conceptual test of category production. The isolation effect was assumed to occur on the category verification test because this test requires the same type of evaluation of category membership (that the isolated item is not a member of the same category as the remaining list items) that was presumably engaged at study. However, the effect was not obtained on the conceptual test of category production because this test does not require the same evaluation of category membership from the time of study. This finding demonstrates that performance on conceptual tests can be dissociated by more specific types of conceptual processes and, incidentally, it provides support for the identification–production test distinction. In addition, recent evidence from studies using younger adults shows that performance on perceptual implicit tests, such as word stem completion, can be distinguished on the basis of the specific identification and production processing demands of the tests (Barnhardt, 2005).

Several findings from implicit memory studies with older adults can be accommodated within the identification–production distinction (but see Prull, 2004). An examination of this literature shows that older adults generally have reduced priming on production tests but not on identification tests (see Fleischman & Gabrieli, 1998, for a review of these findings). Briefly, within the perceptual domain, older adults often show reduced priming on the word stem completion test (Chiarello & Hoyer, 1988; Davis et al., 1990; Hultsch et al., 1991; Winocur et al., 1996; but see Clarys, Isingrini, & Haerty, 2000). However, older adults are generally not impaired on the identification test of perceptual identification (e.g., Light & Prull, 1995) or word fragment completion, in which participants are given degraded versions of words and asked to quickly name them (Light, Singh, & Capps, 1986; Rybash, 1996). Further, a recent meta-analysis of implicit memory studies comparing younger and older adults found that across several studies, age effects were greater for tests that were classified as production tests than those that were classified as identification tests (Light, Prull, La Voie, & Healy, 2000).

The identification–production distinction also gains support from implicit memory studies of patients with clinically diagnosed Alzheimer's disease (AD; Fleischman & Gabrieli, 1998; Gabrieli et al., 1994, 1999). This work shows that older adults with AD have reduced priming on production tests but not on verification or identification tests, regardless of whether the tests require conceptual or perceptual processes (Gabrieli et al., 1999). Gabrieli et al.'s (1999) study showed that, as compared with nondemented older adults, those with AD had reduced priming on the production tests of word stem completion and category production, but intact priming on the verification and identification tests of picture identification and category verification. Further, results showed the same performance dissociation for younger adults when their attention was divided at study. Perhaps most relevant to purposes of the current study, results appear to demonstrate a selective age reduction in production priming. Although priming for younger and older adults was not compared across experiments, examination of the mean priming performance for healthy older adults and younger adults under similar study conditions (full attention) shows an age effect in production priming. In word stem completion, younger adults had 40% priming, whereas older adults had 19% priming. Similarly, in category production, younger adults had 21% priming, whereas older adults had 15% priming. Returning to the main focus of their article, Gabrieli et al. suggested that it is not the conceptual or perceptual nature of the test that determines performance in older adults with AD, but rather the differences in attentional control requirements of the production or verification tests.

The Role of Attention and Frontal Functioning in Production Priming

Older adults, and particularly those with AD, are hypothesized to have reduced production priming because these tests tend to also allow for more response competition than do identification tests.[1] The identification–production distinction has been used to explain both AD and age effects in implicit memory performance (Fleischman & Gabrieli, 1998; Gabrieli et al., 1999). The hypothesis is that healthy older adults, and especially those with early stage AD, have reduced attentional control abilities that limit them from optimally encoding study items. Because production tests allow for multiple correct responses, it is less likely that a studied item will be selected on these tests if the item was not originally well encoded. Take for example the category production and category verification tests. The category production test may allow for response competition because participants are given a category cue (e.g., *Types of Fruit*) that has several viable nonstudied responses (e.g., "apple," "banana," "pear," etc.) in addition to a studied response (e.g., "strawberry"). In contrast, the category verification test may allow for less response competition than category production because the test cue provides information that guides retrieval, typically by providing the actual target item at test. In this task, participants would simply be given a category label and a possible target (e.g., *Types of Fruit: strawberry*) and have to identify the item as either belonging or not belonging to the category. Thus, the idea is that older adults show reduced priming on production tests that allow for response competition because they have limited attentional control abilities that reduce item encoding and selection.

There is indirect support for the hypothesis that attentional control and frontal functioning mediate age effects in priming on production tests with response competition but not on identification tests. Recent neuroimaging work shows that there is differential activation of the frontal lobes for younger and older adults on some priming tasks. For example, increased prefrontal activity is observed during the word stem completion task, particularly for stems with many possible solutions, as opposed to those with fewer solutions (Desmond, Gabrieli, & Glover, 1998). In contrast, other priming tasks, such as the living–nonliving identification task, do not show differential frontal activation for younger and older adults, including older adults with AD (Lustig & Buckner, 2004). The differences in age-related frontal activation patterns across studies could be taken as support for the hypothesis that the frontal lobes mediate age differences in production priming but not in identification priming. Of course, the word stem completion task and the living–nonliving task differ on multiple dimensions that could explain differences in frontal activation. Nonetheless, these data can be taken as support for the hypothesis that the frontal lobes are critical for production priming.

In addition, neuropsychological studies provide additional support for the idea that frontal functioning may be important for priming on production tests that have response competition. For example, older adults' performance on the FAS Verbal Fluency Test FAS; (Spreen & Benton, 1977) and the Wisconsin Card Sorting Test (WCST; Hart, Kwentus, Wade, & Taylor, 1988), two tests assumed to measure attentional control and executive functioning, is related to their level of priming on the word stem completion test, particularly when the test has multiple solutions (Nyberg, Winocur, & Moscovitch, 1997). Although this study was not designed to examine the identification–production test distinction, it does provide evidence for the influence of older adults' frontal functioning on a priming task with production demands. These researchers propose that the frontal lobes are involved in word stem completion priming because age-associated reductions in frontal functioning influence participants' ability to engage in nonconscious word selection at retrieval (Nyberg et al., 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. Frontal functioning is also assumed to allow for the complementary inhibition of the nonstudied competitors. Thus, this hypothesis posits the influence of frontal involvement at a different stage in production tasks than the previously mentioned hypothesis (Gabrieli et al., 1999), which suggests that reduced attention to items at encoding leads to reduced priming under conditions of response competition. Nonetheless, both hypotheses predict that older adults' frontal functioning mediates performance on standard production tests of implicit memory that allow for multiple responses.

Although the hypotheses just described and the data from AD patients together suggest that frontal functioning might mediate production priming in older adults, direct evidence for this hypothesis is lacking. The goal of the current studies is to directly test the hypothesis that frontal functioning mediates the reported age effects in production priming. Production priming was examined for younger adults and older adults who differ in their frontal functioning, as measured by neuropsychological tests of executive functioning and attentional control. Older adults were given a battery of five neuropsychological tests taken from a large factor analytic study of frontal functioning (Glisky, Polster, & Routhieaux, 1995). This particular battery of tests was also used because these tests together are predictive of other types of memory abilities that require attentional control, including source memory (Glisky et al., 1995; Glisky, Rubin, & Davidson, 2001), false memory avoidance (Butler, McDaniel, Dornburg, Price, & Roediger, 2004), and prospective memory (McDaniel, Glisky, Rubin, Guynn, & Routhieaux, 1999). After neuropsychological testing, all participants in the current study were then given two different implicit memory tests that both required production: the perceptual test of word stem completion (Experiment 1a), and the conceptual test of category production (Experiment 1b). As a manipulation check, all participants were given a final free recall test following each implicit test. If frontal lobe mediated processes such as attentional control drive reported age effects on implicit memory tests that require production, then older adults with poor performance on these frontal tests should show reduced priming on both

[1] Production and identification tests also differ in terms of whether they actually require production of a response, but recent work has shown that production processes per se do not mediate age effects on implicit tests (Prull, 2004).

the word stem completion and the category production tests, as compared with older adults with good performance on the frontal tests and with younger adults.

Method

Participants

Fifty-six younger adults (ages 18–22 years) and 56 older adults (ages 65–85 years) participated in the study. Younger adults were recruited from the Psychology Department's undergraduate participant pool, and they received course credit for their participation. Older adults were recruited through the department's community participant pool, and they received money for their participation.

In an earlier testing session, older adults were given a series of five neuropsychological tests that have been shown to measure attentional control associated with frontal lobe functioning (Glisky et al., 1995). These tests included the WCST, the FAS, the Mental Control test taken from the Wechsler Memory Scale—Third Edition (Wechsler, 1987), the Mental Arithmetic test taken from the Wechsler Adult Intelligence Scale—Revised (Wechsler, 1981), and the Digit Span test taken from the Wechsler Memory Scale—Third Edition (Wechsler, 1987). On the basis of participants' performance on each of the tests, a single age-adjusted z score was calculated for each subject to represent his or her level of frontal lobe functioning. The frontal scores were calculated by means of an equation that was derived from Glisky et al.'s (1995) factor analysis that has been described elsewhere (Butler et al., 2004; Glisky et al., 2001; McDaniel et al., 1999). This equation was based on a normative sample tested in Glisky's lab. Participants whose z scores fell above zero were classified as high-frontal functioning ($n = 24$), and those whose scores fell below zero were classified as low-frontal functioning ($n = 32$). On the basis of their performance on the neuropsychological tests, high- and low-frontal functioning older adults returned to the lab to participate (along with a group of younger adults) in the following memory experiment. Thus, there were essentially three participant groups in the following studies: younger adults, high-frontal functioning older adults, and low-frontal functioning older adults.

During the experimental test phase, older adults were also given the 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 28.60 ($SD = 1.38$), and no one in the sample scored lower than 25 on this test. Younger and older adults were also given the Shipley Vocabulary Test (Zachary, 1986) to assess word knowledge. Older adults had higher vocabulary scores ($M = 35.27$, $SD = 3.70$) than younger adults ($M = 32.79$, $SD = 2.48$), $F(1, 108) = 17.16$, $MSE = 9.87$. Education level was higher for older adults ($M = 14.91$, $SD = 2.53$) than younger adults ($M = 13.43$, $SD = .57$), $F(1, 108) = 18.23$, $MSE = 3.30$. Lastly, all participants filled out a demographic questionnaire that included 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

All three groups of participants participated in essentially two experiments, one right after the other. For each experiment, participants studied a list of words and then were given an implicit production task followed by an explicit free recall test. In Experiment 1a, participants were given a perceptual production test of word stem completion followed by a free recall test for the same items, and in Experiment 1b they were given a conceptual production test of category production followed by a free recall test for the same items.

One important issue in the literature is that age effects in priming do not always reflect differences in purely implicit memory processes. That is, whereas implicit tests are assumed to measure unintentional uses of memory, these tests can become contaminated by explicit memory. Given this possibility, the proposed studies were designed to limit the possibility of explicit memory contamination by using several of the procedures outlined in the literature (see Roediger & Geraci, 2003; Roediger & McDermott, 1993). For example, a fairly elaborate cover story was used to disguise the purpose of the implicit tests. In addition, filler tasks (including perceptual judgments or reaction time tests) were given between study and test to encourage participants to interpret the implicit tests as additional reaction time tests in the series. Also, the implicit test list was structured such that it included relatively few studied items (in both experiments, studied items made up one third of the test items) to disguise the purpose of the task and to limit the utility of using an explicit search strategy to perform the task. Even with these precautions in place, participants can become aware of the study–test relationship. Therefore, participants were also given a posttest questionnaire to assess whether participants might have used explicit memory strategies to perform the task.

Materials and Procedure (Experiment 1a: Word Stem Completion)

Two study lists were created from a pool of 120 medium-frequency words. Participants studied 60 medium-frequency words plus 4 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 the focus of the study was on 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 reaction time tasks. As part of the cover story, participants were told that the purpose of the word stem completion task was to measure their reaction time while they awaited the free recall test.

After 15 min of distractor "reaction time" tasks, each participant received the implicit production test of word stem completion (disguised as yet another reaction time test). For this test, they were given a packet with several three-letter word stems (e.g., *app__*) and were told to work as quickly as possible. The word stems were selected such that they would have multiple correct solutions to allow for response competition. Therefore, each word stem had at least three possible medium- to high-frequency (Thorndike & Lorge, 1944) solutions, in addition to the target solution. They were told that there were no correct answers and that they should skip any items that they could not complete within approximately 10 s. They were also warned not to use any words under five letters or any proper nouns to complete the stems. The test included stems that corresponded to 30 words from the study list (unbeknownst to participants), 30 new words, and 30 filler words. The filler words were included to reduce the overall proportion of studied items in the test list, but these words did not meet the same criteria as the studied and nonstudied words (they were not normed and were not counterbalanced across participants). Because only 30 items from the study list were tested, four test versions were created to counterbalance items tested and study status. This test took approximately 8 min.

Immediately after participants finished the word stem completion test, they were given the anticipated free recall test. Participants had 5 min to complete the test, but most were finished within less time. Participants then took a short break, filled out a demographic questionnaire, and older adults took the MMSE. 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 asked to participate 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.

Materials and Procedure (Experiment 1b: Category Production)

A pool of 160 categorized words (8 words from 20 different categories taken from the Battig and Montague, 1969, norms) was divided into two study lists of 80 words (8 category exemplars from 10 categories). Participants studied all 80 words presented in a fixed random order, in which no more than two category exemplars were presented sequentially, plus 4 items from filler categories 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.

After the study session ended, participants participated in an unrelated 5-min reaction time task, and then they were given the implicit production test of category production (disguised as another reaction time test). The test consisted of 15 category labels. Five corresponded to 40 of the studied category exemplars, 5 corresponded to 40 nonstudied category exemplars, and 5 served as filler category labels (again fillers were included to reduce the overall proportion of studied categories in the test list). Participants were given a packet containing the category labels (e.g., *Types of Fruit*) and were told to list as many examples of the given category as possible within the allotted time (30 s). A tone played on a tape recorder signaled when participants were to move on to the next item. Including instructions, this test took approximately 10 min to complete. Because only 40 items from the study list were tested, four test versions were created to counterbalance items tested and study status.

Immediately after participants finished the category production test, they were given the anticipated second free recall test. Again, participants had 5 min to complete the test. At the conclusion of this second free recall test, participants were given a posttest questionnaire to assess their awareness of the connection between each study and test phase. Participants were first asked to list any encoding strategies they used (to disguise the intent of the questionnaire and avoid any awareness bias in posttest responding). Then they were asked to list any factors that might have helped them to perform the word stem completion task and any factors that might have helped them to perform the category production task. Participants were categorized as test-aware if they mentioned the study episode as a factor that might have helped them to perform either task.

Results

The level of significance was set at .05 for all analyses. For each analysis F values, mean square error, and effect size (partial eta squared; η_p^2) are presented. Partial eta squared is an estimate of the proportion of total variability attributable to each factor in the sample. One older adult was removed from the following analyses because of a coding error.

Word Stem Completion (Experiment 1a)

Table 1 shows the mean proportion of word stems correctly completed for studied and nonstudied (base rate) solutions. Results showed that both younger adults, $F(1, 55) = 26.45$, $MSE = .01$, $\eta_p^2 = .33$, and older adults, $F(1, 54) = 23.50$, $MSE = .01$, $\eta_p^2 = .30$, completed significantly more word stems with studied words as compared with nonstudied words (showing significant levels of priming). In contrast to the predictions of the frontal lobe hypothesis of production priming, there was no difference in priming across the three participant groups (younger, low-frontal older, and high-frontal older), $F(2, 108) = 1.52$, $MSE = .01$, $\eta_p^2 = .03$.

A second look at the data reveals small baseline differences for the three groups that can qualify the conclusions one makes from the absolute priming scores. However, when priming was examined as 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), the proportional priming was not statistically different for younger adults ($M = .11$, $SD = .16$), high-frontal older adults ($M = .05$, $SD = .16$), and low-frontal older adults ($M = .12$, $SD = .14$), $F(2, 108) = 1.63$, $MSE = .03$, $\eta_p^2 = .03$.

To more closely examine the role of frontal functioning on priming in the word stem completion task, priming scores for extreme groups of high- and low-frontal functioning older adults were compared. For this analysis, 14 older adults with the highest frontal scores were compared with 14 older adults with the lowest frontal scores. Results from this analysis were similar to the results from the entire group of older adults. Priming for the highest frontal functioning older adults was not statistically different from priming for the lowest frontal functioning older adults, $F(1, 26) = 2.36$, $MSE = .01$, $\eta_p^2 = .08$. In fact, priming scores were slightly greater for the lowest frontal functioning group ($M = .11$) than the highest frontal functioning group ($M = .05$). Thus, even with extreme groups of high- and low-frontal functioning older

Table 1
Word Stem Completion Performance Showing the Proportion Correct for Studied and Nonstudied Targets and Priming Scores for Younger Adults, High-Frontal Older Adults, and Low-Frontal Older Adults

	Study status					
	Studied		Nonstudied		Priming	
Group	*M*	*SD*	*M*	*SD*	*M*	*SD*
Low-frontal older adults	.36	.08	.27	.09	.09	.10
Lowest group	.37	.09	.26	.07	.11	.09
High-frontal older adults	.30	.08	.26	.09	.04	.11
Highest group	.31	.08	.26	.07	.05	.13
Younger adults	.32	.08	.23	.09	.09	.13
Aware	.34	.09	.23	.09	.11	.12
Unaware	.30	.11	.25	.11	.07	.15

adults as participants, the results failed to support the hypothesis that frontal functioning mediates production priming in older adults.

Younger and older adults' responses to the posttest awareness questionnaires were also examined. On the posttest questionnaire, participants were asked to list strategies that they felt may have helped them to perform the various tasks (the implicit tests). Participants were labeled as aware if they mentioned the study list as a factor that may have influenced their performance on either task. Examination of these questionnaires showed that many younger adults mentioned the study list as a factor that contributed to their performance on the implicit tests. In fact, over half of the younger adults reported awareness of the study–test connection (n = 33), whereas only 3 of the older adults, all high-frontal functioning, mentioned the study list in connection to their performance on the implicit tests. Because there were so few test-aware older adults, an analysis of variance was not used to examine the contribution of awareness to priming. However, it is noteworthy that the priming for these 3 high-frontal older adults is numerically higher than the priming for the high- and low-frontal unaware older adults (M = .12, SD = .12 vs. M = .07, SD = .11, respectively). Next, the contribution of awareness to priming in younger adults was examined. The aware and unaware groups do not each contain complete counterbalancing. Therefore, the effect of test version on priming for younger adults was first examined to determine whether these groups could be compared. Results showed that there was no effect of test version on priming, $F(3, 52) = 2.19$, MSE = .01, $\eta_p^2 = .12$, so the contribution of awareness to priming was examined. Although this difference was not significant, $F(1, 54) = 1.78$, MSE = .02, $\eta_p^2 = .03$, aware younger adults showed numerically greater priming (M = .11) than unaware younger adults (M = .07).

Category Production (Experiment 1b)

Table 2 shows the mean proportion of categories completed with studied and nonstudied exemplars. Both younger adults, $F(1, 55) = 176.79$, MSE = .01, $\eta_p^2 = .76$, and older adults, $F(1, 54) = 59.74$, MSE = .01, $\eta_p^2 = .53$, were more likely to produce studied than nonstudied category exemplars (again showing significant levels of priming). In contrast to the results from the word stem completion task, there was an overall effect of participant group on priming for the category production task, $F(2, 108) = 11.98$, MSE = .01, $\eta_p^2 = .18$. Planned comparisons showed that this effect was driven by a significant age effect, $F(1, 109) = 23.75$, MSE = .01, $\eta_p^2 = .18$, showing that younger adults had significantly more priming on this task than older adults (younger, M = .20, SD = .11; older, M = .10, SD = .10). Again, the proportional priming was analyzed. Results from these analyses converged with the absolute priming data and show greater priming for younger adults (M = .25, SD = .14) than for older adults (M = .12, SD = .12), $F(1, 109) = 26.05$, MSE = .02, η_p^2 = .19. Thus, the overall priming results demonstrate an age effect in category production priming but not in word stem completion priming. Although this finding was not specifically predicted, it is consistent with the hypothesis that age influences performance on conceptual tests but not perceptual tests (Jelicic, 1995; Jelicic et al., 1996; Rybash, 1996).

As in the word stem completion analyses, the contribution of study–test awareness to priming was examined for category production priming. Visual inspection of the 3 older adults reporting awareness showed that they had numerically higher priming than the unaware older adults (aware, M = .16, SD = .03; unaware, M = .10, SD = .10). However, because the sample was so small, the data were not analyzed separately for these participants. Turning to the effect of awareness on priming for the younger adults, again results showed that there was no effect of test version on priming, $F(3, 52) = 2.19$, MSE =.01, $\eta_p^2 = .11$. Given the lack of a list effect, priming was compared for the aware and unaware groups. This time, results showed that priming was significantly greater for test-aware younger adults than for test-unaware younger adults, $F(1, 54) = 6.06$, MSE = .01, $\eta_p^2 = .10$. Thus, the level of priming in this task appears to be driven in part by awareness; priming for the test aware younger adults (n = 33) was .23, whereas priming for the test-unaware younger adults (n = 23) was .16. Despite the contribution of awareness to priming in this group, when just the unaware younger adults were compared with the older adults, the age effect remained, $F(1, 76) = 4.39$, MSE = .01, $\eta_p^2 = .06$. Therefore, if the failure to mention the study list on the posttest questionnaires can be taken as evidence for a lack of

Table 2
Category Production Performance Showing the Proportion Correct for Studied and Nonstudied Targets and Priming Scores for Younger Adults, High-Frontal Older Adults, and Low-Frontal Older Adults

	Study status					
	Studied		Nonstudied		Priming	
Group	*M*	*SD*	*M*	*SD*	*M*	*SD*
Low-frontal older adults	.24	.10	.15	.05	.09	.10
Lowest group	.20	.08	.16	.04	.04	.09
High-frontal older adults	.33	.12	.22	.08	.11	.09
Highest group	.34	.13	.22	.09	.12	.09
Younger adults	.41	.12	.22	.07	.20	.11
Aware	.46	.10	.23	.06	.23	.09
Unaware	.35	.11	.19	.07	.16	.12

test awareness, then there is an age effect even when participants are not using explicit strategies to recall.

Turning to the critical analysis of frontal functioning on production priming, results showed that there was no effect of older adults' frontal functioning on category production priming, $F(1, 53) = 2.33$, $MSE = .01$, $\eta_p^2 = .01$. However, when priming scores for extreme groups of high- and low-frontal functioning older adults were compared, results showed that priming for the highest frontal functioning older adults ($n = 14$) was significantly greater than priming for the lowest frontal functioning older adults ($n = 14$), $F(1, 26) = 5.29$, $MSE = .01$, $\eta_p^2 = .17$. Priming scores for the highest frontal functioning group ($M = .12$) were more than double the priming scores for the lowest frontal functioning group ($M = .04$). Thus, these data provide evidence that frontal functioning influences category production priming, at least in cases of high differentiation of frontal functioning.

Free Recall

Table 3 shows the proportion of words correctly recalled for both experiments. There was a significant effect of participant group on the proportion of words recalled for both Experiment 1a, $F(2, 108) = 32.93$, $MSE = .01$, $\eta_p^2 = .38$, and Experiment 1b, $F(2, 108) = 24.21$, $MSE = .02$, $\eta_p^2 = .31$. Planned comparisons showed that, as expected, younger adults had better recall performance than older adults for Experiment 1a, $F(1, 109) = 63.04$, $MSE = .01$, $\eta_p^2 = .37$, and Experiment 1b, $F(1, 109) = 46.07$, $MSE = .02$, $\eta_p^2 = .30$. Also, as expected, high-frontal lobe functioning older adults had better free recall performance than low-frontal lobe functioning older adults in Experiment 1a, $F(1, 53) = 4.53$, $MSE = .01$, $\eta_p^2 = .08$, and in Experiment 1b, using a one-tailed test, $F(1, 53) = 3.04$, $MSE = .01$, $\eta_p^2 = .05$.

Taken together, these results show that explicit memory performance was affected by age and older adults' frontal functioning (showing that younger adults had the best free recall performance, whereas low-frontal older adults had the worst free recall performance). Implicit memory results show that category production, but not word stem completion priming, was affected by age and frontal functioning.

Discussion

The current study was designed to examine whether older adults' priming on production tests of implicit memory is mediated by processing declines associated with reduced frontal lobe functioning (Fleischman & Gabrieli, 1998; Gabrieli et al., 1999). The current study directly tested this hypothesis of production priming using younger adults and older adults who differed in their attentional control abilities, as measured by performance on a battery of neuropsychological tests. Results showed that frontal functioning did not influence word stem completion priming but did influence category production priming, when extreme groups of older adults were considered. Similarly, age reduced priming on the category production test but not on the word stem completion test. In contrast to the word stem completion data, explicit memory performance on free recall tasks showed both an effect of age and frontal lobe functioning. These free recall data are consistent with a recent computational model showing that self-organization processes associated with prefrontal cortex functioning are critical for performance on free recall tasks (Becker & Lim, 2003). As expected, younger adults had the best free recall performance, followed by high-frontal older adults who had better recall than low-frontal older adults. Thus, the results showed an effect of frontal functioning in explicit memory and conceptual production priming but not word stem completion priming. These results are inconsistent with the identification–production account of frontally mediated age declines in priming.

It is not clear why age affected priming on the category production task but not on the word stem completion task. Although some researchers have proposed that age affects priming on conceptual but not perceptual implicit tests (e.g., Jelicic, 1995; Jelicic et al., 1996; Rybash, 1996), including the test of word stem completion (see Clarys et al., 2000), there is research that is inconsistent with this hypothesis (see Light, Prull, & Kennison, 2000) and the age effects obtained in the present study. For example, other studies show that age does reduce priming on the word stem completion test (e.g., Chiarello & Hoyer, 1988; Davis et al., 1990; Hultsch et al., 1991; Winocur et al., 1996). Further, this reduction in perceptual priming is sometimes accompanied by equivalent conceptual priming (Small et al., 1995). For example, some research demonstrates age equivalence on the category production test (Light, Prull, & Kennison, 2000) and a recent meta-analysis failed to find evidence for a differential age reduction in conceptual priming (Light, Prull, La Voie, & Healy, 2000). Thus, it is difficult to know definitely why age sometimes does and does not affect word stem completion or category production priming. In the current study, it is possible that the age and frontal reduction in category production occurred because the study words for this test were categorized, whereas the study words for the word stem completion test were unrelated. Younger adults may be more likely than older adults to spontaneously encode and use category relationships to aid memory (e.g., Hultsch, 1975), which may have helped boost younger adults' conceptual priming.

Although this semantic organization theory could account for the pattern of data, the effect of frontal functioning on category production priming is also consistent with research showing that the left prefrontal cortex is involved in selection of semantic information under conditions of response competition (Thompson-Schill, D'Esposito, Aguirre, & Farah, 1997; Thompson-Schill, D'Esposito, & Kan, 1999; Thompson-Schill et al., 1998). In one study that used a semantic priming task (Thompson-Schill et al., 1999), participants were given nouns and either made the same or different semantic judgments across study and test phases (e.g., generating a color or an action associated with the noun). In both cases, priming was observed: Participants were faster to make

Table 3
Free Recall Performance for Younger Adults, High-Frontal Older Adults, and Low-Frontal Older Adults

Group	Exp. 1a *M*	Exp. 1a *SD*	Exp. 1b *M*	Exp. 1b *SD*
Low-frontal older adults	.09	.06	.20	.09
High-frontal older adults	.15	.11	.25	.12
Younger adults	.30	.15	.38	.15

Note. Exp. = experiment.

judgments to studied items than nonstudied items, and this effect was greater for the items for which participants made the same judgments across study and test than items for which they made difference judgments across study and test. However, the functional magnetic resonance imaging data showed differential involvement of the frontal lobes across the same and different judgment conditions. There was a decrease in activation in the prefrontal cortex in the same judgment condition when response competition was low (when the required test response was the same as at study) but an increase in activation in this area in the different judgment condition when response competition was high (when the required test response was different from the prepotent studied response). These results showing that the prefrontal cortex mediates selection from semantic memory are consistent with the current data showing a selective frontal effect in category production. The results from older adults with AD are even more compelling. For example, older adults with AD who are assumed to have declines in frontal functioning show greater impairment on several semantic generation tasks, including FAS, when there is a high degree of competition among possible responses (Tippett, Gendall, Farah, & Thompson-Schill, 2004). The interpretation is that executive processing deficits associated with AD selectively impair attention-demanding retrieval from semantic memory. The selective influence of frontal functioning on category production priming is consistent with this body of work showing frontally mediated impairments in conceptual processing under conditions of response competition.

Finally, the frontal effect in category production, but not word stem completion, could be explained by differences in the amount of response competition across the two tasks. In word stem completion priming, the average number of possible responses was approximately seven, whereas in category production the average number of possible responses was much higher. On the basis of the norms (Battig & Montague, 1969) of the categories that were used in the current study, the average number of solutions for each test category was approximately 36. Thus, this difference in amount of response competition could explain the differential influence of age and frontal functioning in the two tests. Indeed, the baseline differences across tests support this hypothesis. Overall baseline performance for older adults was .26 for the word stem completion task, and .17 for the category production task, indicating that there may have been more response competition present in the category production task. In fact, the low-frontal older adults showed lower baseline performance than the high-frontal older adults on this task overall, further suggesting that frontal functioning might relate specifically to processes associated with resolving response competition. Additional work is needed to directly examine the role of response competition in mediating age effects in priming. For now, the current pattern of data simply suggests that the identification–production test distinction does not explain frontally mediated age effects in priming. In the present study, older adults, and particularly those with poor frontal functioning, were impaired on one production priming task but not another.

The lack of a frontal effect on word stem completion priming is inconsistent with results showing that older adults' priming on this task is correlated with performance on the FAS (Winocur et al., 1996) and the WCST (Nyberg et al., 1997), two tests that have been associated with frontal lobe functioning. It is not clear how to reconcile these findings with the current data. One possibility is that performance on the FAS and the WCST alone relate to word stem completion priming. Word stem completion priming in the current study was correlated with participants' FAS performance and their WCST performance separately to examine this possibility. However, when the correlation between priming and performance on each task was examined individually, results failed to show a correlation between word stem completion priming and performance on either the FAS test, as measured by the number of words output ($r = -.13$), or performance on the WCST, as measured by the number of categories achieved (the measure used in this battery; $r = -.03$) or the perseverative errors (the measure used in Winocur et al.'s, 1996, study; $r = 13$). Another possibility is that the sample of participants in the current study contained older adults with overall higher levels of frontal functioning, as measured by FAS and WCST performance, than those used in Winocur et al. and Nyberg et al.'s (1997) studies. However, the level of overall frontal functioning does not appear to be a viable explanation because the average FAS score in the current study ($M = 41.25$, $SD = 11.77$) is almost identical to the average FAS score for the older adults in Nyberg et al.'s study ($M = 42.51$, $SD = 9.77$). In addition, the average number of perseverative errors in the current study ($M = 10.30$, $SD = 11.10$) is actually higher than the average number of errors in Winocur et al.'s study ($M = 8.82$ averaged across the two groups of older adults). Further, the average number of perseverative errors for the low-frontal older adults in the current study ($M = 13.35$, $SD = 13.20$) is slightly higher than the average number of perseverative errors for the group of institutionalized older adults in Winocur et al.'s study ($M = 11.92$), whose performance was significantly correlated with priming in that study. Thus, it seems unlikely that the level of frontal functioning explains the disparate pattern of findings for the word stem completion test across the current study and Nyberg et al. and Winocur et al.'s studies. Indeed, previous work had also failed to find an influence of frontal functioning on word stem completion priming. This work demonstrated equivalent priming in word stem completion for patients with frontal lobe lesions and healthy older adults (Shimamura, Gershberg, Jurica, Mangels, & Knight, 1992).

The disparate findings across studies examining frontal functioning and word stem completion priming could be explained by differential use of explicit memory strategies. Here, one can speculate that the FAS and WSCT correlations with word stem completion in Nyberg et al. (1997) and Winocur et al.'s (1996) studies might reflect some contribution of explicit strategies to the priming task. For example, results from both studies showed that performance on the frontal-functioning tests of the FAS and the WCST were correlated only with performance for studied word stems and not nonstudied word stems with multiple solutions. Although this finding is consistent with the authors' interpretation that frontal functioning is specifically related to priming, this finding is also consistent with the idea that frontal functioning is related to strategic efforts to retrieve studied items. Because there were no measures taken to avoid or assess explicit contamination in these studies, the real source of the discrepant results cannot be determined. However, the current study went to great lengths to limit the possibility of awareness and explicit retrieval strategies and found no correlation between priming and frontal functioning using two different implicit tests that require production.

The issue of explicit contamination is particularly important when examining age effects in implicit memory because younger and older adults differ in their abilities to use explicit memory strategies. The idea is that many age effects in implicit memory are partly driven by younger adults augmenting their performance on presumably implicit tests with explicit strategies (Habib, Jelicic, & Craik, 1996; Light, 1991; Mitchell, 1995; Mitchell & Bruss, 2003; Russo & Parkin, 1993). Indeed, it has been suggested that awareness occurs at different rates across different age groups (see Mitchell & Bruss, 2003). The current study also showed that older and younger adults differed greatly in their reports of awareness. Although over half of the younger adults reported awareness of the study–test connection on the posttest questionnaire, only 3 of the 56 older adults reported awareness of this connection. Indeed, one possible explanation for the previously reported dissociation between older adults' performance on production and identification implicit tests could be that younger adults may be more likely to use explicit strategies to perform production tests than identification tests. Certainly, identification tests might be less likely to allow for strategic retrieval processes than production tests because these tests are often speeded. Although posttest questionnaires may be imperfect measures of online awareness and the actual use of explicit strategies during test, they have been used to show important dissociations as a function of explicit contamination (Geraci & Rajaram, 2002) and thus may offer some insight into the mixed reports of age effects on implicit production tests.

The current study does not support the hypothesis that differences in older adults' frontal functioning mediate age effects in production priming. Using two different implicit tests that required production and response competition, word stem completion and category production, the present study's results showed an effect of frontal functioning in category production priming but not in word stem completion priming. This pattern of data suggests that another processing distinction, other than the identification–production distinction, is needed to explain the pattern of aging effects in priming. Future work will need to isolate these critical processes. Although production priming does not seem to be mediated generally by frontal functioning in healthy older adults, it remains to be seen whether frontal functioning uniquely influences production priming in older adults with AD. Regardless, the current study provides an important step towards understanding the contribution of frontal functioning to age effects in priming.

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