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Auditory Priming in Elderly Adults: Impairment of Voice-specific Implicit Memory

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Previous research has shown that elderly adults often exhibit intact priming effects on visual implicit memory tests, but little is known about auditory priming and ageing. We examined priming effects on auditory stem-completion and filter identification tasks in older and younger adults. Young subjects showed more priming when speaker's voice was the same as study and test than when it differed, but elderly subjects failed to exhibit this voice-specific priming effect in each of five experiments. The elderly did, however, show robust nonspecific priming. We attempt to rule out hearing deficit accounts of the priming impairment and consider alternative theoretical interpretations of the effect.

INTRODUCTION

A large body of experimental evidence indicates that elderly adults exhibit memory impairments on tasks that require conscious or explicit recollection of recent experiences, such as standard laboratory tests of recall and recognition (Light, 1991). During the past several years, however, a growing number of studies have examined whether age-related deficits are also observed on tests that do not require conscious recollection of previous experiences, such as completing word fragments or identifying briefly exposed words. On these indirect or implicit memory tests (Graf & Schacter, 1985; Schacter, 1987), memory is inferred from the existence of *priming effects*: facilitated production or identification of recently presented items from degraded perceptual cues

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(Tulving & Schacter, 1990; for recent reviews, see Roediger & McDermott, 1993; Schacter, Chiu, & Ochsner, 1993).

A number of studies have shown normal levels of priming in elderly adults relative to young subjects (Howard, Fry, & Brune, 1991; Light et al., 1992; Light & Singh, 1987; Light, Singh, & Capps, 1986; Mitchell, 1989; Mitchell, Brown, & Murphy, 1990; Moscovitch, 1982; Schacter, Cooper, & Valdiserri, 1992). In contrast, other studies have reported relatively small age-related priming deficits together with much larger impairments of explicit memory (Chiarello & Hoyer, 1988; Davis et al., 1990; Hultsch, Masson, & Small, 1991). However, one problem with these latter studies is that apparent age-related priming deficits may have been attributable to the use of intentional, explicit retrieval strategies by young subjects. Because none of the studies contains the necessary control conditions to rule out such a possibility (for discussion, see Graf, 1990; Jennings & Jacoby, in press; Light & La Voie, 1993; Schacter, Bowers, & Booker, 1989; Schacter, Kihlstrom, Kaszniak, & Valdiserri, 1993), the question of whether there are "genuine" age-related priming deficits remains open.

Almost all studies of perceptual priming in elderly adults have used visual materials and visual tests. Accordingly, inferences about priming and ageing have been based almost entirely on data concerning vision-based processes and systems. In order to develop a broad understanding of the status of implicit memory in ageing, it would be desirable to obtain data from modalities other than vision. One study that provides such data has been reported recently by Light et al. (1992). In their experiment, young and old subjects either heard or saw a series of target words, and were then given an auditory identification test in which both studied and nonstudied words were presented in white noise. Three important outcomes were observed on the identification test: 1. priming was greater for previously heard words than for previously seen words (modality-specific priming); 2. there was significant priming for previously seen words (modality-nonspecific priming); and 3. old and young subjects exhibited virtually identical amounts of both modality-specific and modality-nonspecific priming. By contrast, elderly adults were significantly impaired on an explicit measure of memory for presentation modality.

The results reported by Light et al., then, suggest that auditory priming may be fully preserved in elderly adults. Before accepting this conclusion, however, it is useful to consider these data in light of experiments that have been conducted on auditory priming in young subjects. The most relevant conditions are ones that allow comparison of priming when the speaker's voice is the same or different at study and test. Jackson and Morton (1984) found that priming on an identification-in-noise test was unaffected by study-to-test changes in speaker's voice (i.e. female–male *vs* female–female). However, like Light et al., they also found that prior auditory presentation of target words produced more priming on the identification-in-noise test than did prior visual presentation, although there was still some priming from visual presentation. Thus, Jackson and Morton's data from young subjects suggest that priming on the identification-in-noise test is *modality specific* but not *voice specific*.

Consistent with the Jackson and Morton results, we (Schacter & Church, 1992, Experiments 1 & 2) also found that study-to-test changes in speaker's voice do not significantly affect priming on the identification-in-noise test, even following encoding tasks that direct subjects' attention to acoustic features of the voice. Importantly, however, we did find significant voice-change effects on an auditory stem-completion test. Here, initial syllables of studied and nonstudied words are spoken in the clear (i.e. without any noise), and subjects respond with the first word that comes to mind (Schacter & Church, 1992, Experiments 3 & 4). We found more priming when voices were identical at study and test (i.e. male–male, female–female) than when they differed (i.e. female–male, male–female). However, when we added white noise to the stems in a subsequent experiment, the voice change effect was eliminated (Schacter & Church, 1992, Experiment 5). In more recent work, we have found strong evidence for voice-specific priming on an auditory identification test in which words are degraded with a low-pass filter and no white noise is used (Church & Schacter, 1994). Based on these results, we have argued that auditory priming contains a voice-specific component, and that the presence of white noise on identification or completion tests interferes with the expression of the stored voice information that underlies this component of priming (for further discussion, see Church & Schacter, 1994; Schacter, 1994; Schacter & Church, 1992).

The foregoing experiments have implications for interpreting Light et al.'s (1992) data. The results with young subjects indicate that the identification-in-noise task used by Light et al. yields *modality-specific priming* but not *voice-specific priming*. However, other implicit tests, such as auditory stem-completion and filter identification, have provided evidence for voice-specific priming in young subjects. Thus, to determine whether auditory priming is fully preserved in the elderly, it is necessary to examine whether older adults exhibit normal voice-specific priming under conditions that are known to yield voice-specific priming in young subjects.

These considerations also bear on Light et al.'s suggestion that the modality-specific component of priming constitutes an indirect measure of memory for context. Because elderly adults exhibit intact modality-specific priming, the inference is that they can represent contextual information normally at some level, but have difficulties recollecting it consciously. Note, however, that modality-specific auditory priming, in contrast to voice-specific priming, might be mediated by the activation of relatively abstract (but modality-specific) auditory word forms independently of the particular voice or context in which target words were presented (see Jackson & Morton, 1984; Morton, 1979). Thus, the demonstration of normal modality-specific priming in elderly adults need not imply indirect or implicit access to the specific details of a perceptual encounter with a word. A comparison with visual word identification performance may help to clarify the point. Although priming on the visual word identification test appears to be entirely modality specific (e.g. Jacoby & Dallas, 1981), effects of within-modality changes of perceptual features like typefont and handwriting are small and sometimes difficult to observe (cf Graf & Ryan, 1990; Jacoby & Hayman, 1987). Therefore, the within-modality component of visual priming may be driven in part by activation of relatively abstract visual representations, and in part by more specific visual representations (for discussion, see Carr, Brown, & Charalambous 1989; Schacter, 1990, 1994). The data reviewed earlier suggest that a similar distinction between abstract and specific perceptual representations applies to auditory priming. Accordingly, a demonstration of intact voice-specific priming in older adults would constitute more compelling evidence for implicit access to context-specific information than does the demonstration of intact modality-specific priming on an implicit test (identification in white noise) that does not yield evidence of voice-specific priming.

This article describes five experiments in which we examine whether older adults exhibit voice-specific priming on auditory implicit tests that yield evidence of voice specificity in younger subjects. Experiments 1 and 2 use an auditory stem-completion test, and Experiments 3–5 use an auditory filter identification test. In all experiments, voice-specific priming is indicated by higher levels of completion or identification performance when speaker's voice is the same at study and test than when it differs. To anticipate our results, all five experiments demonstrate nonspecific word priming effects in older adults, but none of them provides evidence of voice-specific priming in the elderly.

EXPERIMENT 1

In this experiment, older and younger subjects heard a series of words spoken by six different speakers, three male and three female. After a brief distractor task, subjects were given an auditory stem-completion test in which the first syllable of studied and nonstudied words was presented, and they were instructed to respond with the first word that came to mind. Half of the stems from the studied items were presented in the same voice as during the study task, and half were presented in a different voice; voice change always involved a change in the speaker's gender. Subjects were then given a cued recall test in which the same nominal cues were presented together with explicit memory instructions to try to remember the target word from the study list.

We also included two different encoding tasks, one semantic (rating the number of meanings for each word) and one nonsemantic (rating the clarity with which the speaker enunciates the word). Previous research has shown that the magnitude of priming effects on identification and completion tests is similar after semantic and nonsemantic encoding, even though explicit memory is much higher after semantic encoding than after nonsemantic encoding (cf Bowers &

Schacter, 1990; Graf & Mandler, 1984; Roediger, Weldon, Stadler, & Riegler, 1992; Schacter & Church, 1992). The finding that depth of encoding has large effects on explicit memory and little or no effect on implicit memory provides an internal control against the possibility that priming is "contaminated" by explicit memory strategies: if subjects are engaging in explicit retrieval on a nominally implicit test, then priming should be significantly influenced by depth of processing (Schacter et al., 1989). Because such issues have arisen in previous studies of priming and ageing, it seemed important to include the encoding task manipulation in our experiment.

Method

Subjects. Forty-eight elderly subjects participated in the experiment. They were recruited from advertisements that were placed in local papers and were paid $10.00/hr for their participation in this and other unrelated experiments. Forty eight young subjects also completed the experiment. They were recruited by sign-up sheets posted in the psychology department at Harvard University, and were paid $5.00 for their participation in the experiment. Young subjects ranged in age from 18–25 years. Data from these subjects have been reported separately by Schacter and Church (1992).

Elderly subjects passed (at 80% or better accuracy) a speech discrimination test consisting of repeating words and phrases from the Boston Diagnostic Aphasia Examination Repetition subtest (Goodglass & Kaplan, 1983) that were spoken by the experimenter. In addition, all elderly subjects were interviewed individually to rule out those with a history of alcoholism or substance abuse; recent myocardial infarction; cerebrovascular accident; present or previous treatment for acute or chronic psychiatric illness; syphilis; brain damage sustained earlier from a known cause (e.g. hypoxia); metabolic or drug toxicity; and primary degenerative brain disorders (e.g. Alzheimer's disease, Parkinson's disease, or Huntington's disease).

Subjects either completed a semantic encoding task (rating the number of word meanings) or a nonsemantic encoding task (rating clarity of enunciation). Elderly subjects in the semantic encoding condition had a mean age of 68.04 years (SD = 4.57; range = 61–79), and they had on average 14.79 years of education (SD = 2.47; range = 12–18). On the Weschler Adult Intelligence Scale–Revised, they achieved a mean score of 59.25 (SD = 9.29; range = 42–69) on the vocabulary subtest, and a mean score of 22.5 (SD = 4.52; range = 13–29) on the information subtest. Elderly subjects in the nonsemantic encoding condition had a mean age of 67.25 years (SD = 4.66; range = 60–78), and they had on average 14.92 years of education (SD = 3.34; range = 8–20). They achieved a mean score of 62.75 (SD = 7.01; range = 38–69) on the WAIS–R vocabulary subtest, and a mean score of 24.04 (SD = 3.07; range = 13–29) on the information subtest. There were no significant differences between the two elderly groups on any of these measures, and all of the WAIS–R measures indicate normal performance.

Materials. The target materials consisted of 48 familiar words (see Schacter & Church, 1992, for details) that were divided into two subsets of 24 words each. All of the words had first syllables that allowed at least three possible completions, and the two subsets were matched for frequency, first letter, number of syllables, number of possible completions from the first syllable, and length (Graf & Williams, 1987; Kucera & Francis, 1967). The words were recorded by six speakers, three female and three male. Each word was recorded once by a man and once by a woman, so that voice changes between study and test always included a change in speaker's gender. The words were recorded into a Macintosh computer using a MacRecorder. For the implicit stem completion task the computer was used to edit each word so that only the first syllable was preserved. The words and stems were played at a normal conversational level to the subjects. There were two versions of each study list, two versions of the auditory stem-completion test, and two versions of the cued-recall test; each item was spoken by a male voice on one version and a female voice on the other.

Each study list tape included 24 words spoken clearly. The auditory stem-completion test included the first syllables of 48 words, 24 that had been presented on the study list and 24 that had not been presented previously. The same materials were used for the cued-recall test. We presented the tapes on a stereo cassette deck with headphones.

Design and Procedure. We used a mixed factorial design in which the between-subjects variables were encoding task (semantic *vs* nonsemantic) and age (young *vs* old). The within-subjects variables were speaker's voice (same *vs* different), item type (studied *vs* nonstudied) and type of test (stem-completion and cued-recall). The experiment was completely counterbalanced such that each item appeared equally often in each of the experimental conditions defined by the orthogonal combination of the experimental variables. In addition, each item was spoken equally often by a man and a woman.

All subjects were tested individually. Subjects were given a booklet containing response sheets for each section of the experiment. During the encoding task, 24 words were presented auditorily. Subjects in the nonsemantic encoding condition were asked to rate the speaker's clarity of enunciation on a four-point numeric scale, (1 = poorly enunciated; 4 = well enunciated), whereas subjects in the semantic encoding condition were asked to judge the number of meanings for each word on a four-point scale (1 = one word, 4 = four or more words). There were five seconds between items for subjects to make their ratings.

Subjects then performed a distractor task during which they generated the names of 15 cities beginning with the letters given in their booklets. The task required approximately three to four minutes to complete. After the distractor task, subjects were told that they would be hearing a series of word beginnings and that their task was to complete each stem with the first word that came to mind. There were seven seconds between the items for subjects to write down their answers. Although previous research had indicated that young subjects have no difficulty hearing the stems and producing responses to all of them, pilot data suggested that elderly adults might have difficulties perceiving the stems and hence providing a completion for all of them. Accordingly, we instructed older subjects to write down the stem if they could not think of a completion for it. Young subjects completed virtually all stems, so we were able to infer misperception of the stem when they produced a target response that was phonologically incompatible with the stem.

Once subjects had finished the stem-completion task they were given a cued-recall test. They heard 48 stems and were asked to complete them with words that they remembered from the initial encoding task. They were informed that all of the stems had just been presented during the completion task, and that they should try to remember only items that had appeared in the initial encoding task. Guessing was allowed but not encouraged. There were seven seconds for subjects to respond. As on the completion test, we asked elderly subjects to write down the stems in those cases where they could not recall the item. After finishing the cued-recall test, all subjects were debriefed concerning the nature and purpose of the experiment.

Results

Stem completion. Table 1 presents the proportion of studied and nonstudied stems completed with target items. The completion data were initially analysed in two ways: conditionalised on correct stem-perception, and unconditionalised so that all responses were included. The pattern of results for both old and young subjects was identical in the two analyses. Nevertheless, older adults misperceived more stems than did the young, so we report analyses of the conditionalised data. To correct for stem misperception, all proportions were computed by dividing the number of target completions that each subject provided by the number of syllables that they perceived correctly in each condition. Thus, for example, if a subject misperceived three nonstudied stems, his or her number of target completions would be divided by 21 instead of the total of 24 nonstudied stems that were presented. For nonstudied (i.e. baseline) items, proportion of misperceived stems was 0.22 for old subjects and 0.05 for young subjects $t(94)=8.57$, $P<0.0001$. For studied items, proportion of misperceived stems was 0.23 for old subjects and 0.03 for young subjects, $t(94)=8.87$, $P<0.0001$. Within the studied items, the proportion of misperceived stems was virtually identical in same- and different-voice conditions for both old and young subjects.

TABLE 1
Priming Scores and the Proportion of Nonstudied Target Words Reported on the Auditory Stem-Completion Test as a Function of Age, Encoding Task, and Speaker's Voice in Experiment 1

	Old			*Young*		
	Speaker's Voice			*Speaker's Voice*		
Encoding Task	*S*	*D*	*NS*	*S*	*D*	*NS*
Meaning	0.12	0.13	0.09	0.31	0.18	0.18
Clarity	0.13	0.14	0.08	0.28	0.20	0.14

S = Same, D = Different, NS = Nonstudied

Table 1 indicates that baseline completion rates were lower for the elderly (0.09) than in the young (0.16), $t(94)=5.55$, $P<0.0001$, even though misperceived stems were eliminated. Both subject groups, however, showed clear evidence of priming. Separate analyses for old and young that compared the proportion of target completions for studied and nonstudied items revealed highly significant priming effects for both groups; for old, $t(47)=7.61$, $P<0.0001$; for young, $t(47)=15.75$, $P0.001$. The magnitude of priming for studied words is indicated in Table 1 by *priming scores* that are computed by subtracting the proportion of nonstudied items completed with target words (i.e. baseline completion rate) from the proportion of studied items completed with target words (the overall proportion of studied items completed with target words can thus be computed by adding together the priming scores and baseline completion rates). Consideration of the priming scores for old and young as a function of the experimental manipulations reveals two important facts. First, the encoding task manipulation had no effect on priming in either old or young subject groups; nearly identical amounts of priming were observed following both meaning and clarity encoding tasks. Second, whereas the young subjects showed more priming in the same-voice condition than in the different-voice condition following both encoding tasks, the elderly groups showed no evidence of voice-specific priming following either encoding task.

These impressions were confirmed by an analysis of variance that was performed on the priming scores from the various experimental conditions. There was a nonsignificant main effect of Encoding Task, $F<1$, and this variable did not enter into any significant interactions, all Fs<1. There was, however, a significant interaction between Subject Group and Speaker's Voice, $F(1,92)=7.93$, $MSe=0.011$, $P<0.01$, confirming that young but not old subjects exhibited voice-specific priming. A separate analysis of the young subjects' data revealed a significant main effect of Speaker's Voice, $F(1, 46)=28.32$, $P<0.001$, $MSe=0.009$, whereas there was no hint of a voice effect in the old subjects' data, $F<1$.

To determine whether the age differences that are clearly evident in the voice-specific component of priming are also evident in the nonspecific component, we performed a separate analysis of priming in the different-voice condition. Comparison of studied and non-studied items revealed significant priming in the different voice condition for both old, $t(47)=5.45$, $P<0.0001$, and young, $t(47)=10.83$, $P<0.0001$. Consideration of the mean priming scores in the different-voice condition revealed a trend for greater nonspecific priming in the young than in the old. An ANOVA that was performed on the priming scores in the different-voice condition revealed a significant effect of Age, $F(1,92)=7.94$, $MSE=0.019$, $P<0.01$, with no other effects approaching significance, $Fs<1$.

Cued recall. Table 2 presents the data from the cued-recall test, with misperceived stems excluded, just as on the completion test. The proportion of study list targets provided to stems of nonstudied words is displayed in Table 2 together with corrected recall scores that are computed by subtracting this baseline guessing rate from the proportion of studied items completed with target words (the overall proportion of recalled studied items can thus be computed by adding together the corrected recall scores and the guessing rates). The results are reasonably clear-cut: cued recall performance was affected by encoding task and age but not by voice change.

The overall baseline guessing rate for older adults (0.02) was lower than for young subjects (0.14), suggesting that the elderly used a more conservative response criterion than did the young. Nevertheless, even when the guessing rates were subtracted from the proportion correct for studied items, substantial age differences in corrected recall scores were observed. An analysis of variance was performed on the corrected recall scores, and it revealed a significant main effect of Age, $F(1,92)=99.67$, $MSE=0.053$, $P<0.0001$, indicating more accurate recall for young than old; and a significant effect of Encoding Task, $F(1,92)=20.49$, $MSe=0.053$, $P<0.0001$,

TABLE 2
Corrected Recall Scores and the Proportion of Nonstudied Target Words Reported on the Auditory Cued-Recall Test as a Function of Age, Encoding Task, and Speaker's Voice in Experiment 1

	Old			*Young*		
	Speaker's Voice			*Speaker's Voice*		
Encoding Task	*S*	*D*	*NS*	*S*	*D*	*NS*
Meaning	0.19	0.18	0.02	0.54	0.51	0.08
Clarity	0.09	0.12	0.01	0.22	0.22	0.20

S = Same, D = Different, NS = Nonstudied indicating more accurate recall after the meaning encoding task than after the clarity encoding task for both subject groups. There was also a significant Age × Encoding Task interaction, $F(1,92)=4.82$, $MSe=0.053$, $P<0.05$. reflecting the fact that the recall performance of young subjects improved more than did the performance of old subjects in the semantic encoding condition relative to the nonsemantic encoding condition. No other effects approached significant (all Fs<1.32).

A combined ANOVA that was performed on the priming scores and corrected recall scores revealed several interactions involving Type of Test. The Type of Test × Speaker's Voice interaction, $F(1,92)=6.48$, $MSe=0.013$, $P<0.02$ indicates that voice change affected priming but not cued recall; the Type of Test × Encoding Task interaction, $F(1,92)=21.85$, $MSe=0.026$, $P<0.0001$, indicates that encoding task affected cued recall but not priming; and the Type of Test × Age interaction, $F(1,92)=40.54$, $MSe=0.026$, $P<0.0001$, indicates that the elderly were more impaired on cued recall than on stem completion.

Discussion

The critical result of Experiment 1 is that both old and young subjects exhibited significant priming effects on the auditory stem-completion task, but only young subjects exhibited voice-specific priming. Elderly adults failed to exhibit any evidence of voice-specific priming in either the meaning encoding condition or the clarity encoding condition. By contrast, both old and young subjects exhibited significant nonspecific priming effects in the different voice condition. Although older adults appeared to show less nonspecific priming than did young subjects, we must be cautious about interpreting this finding. Specifically, although elderly adults exhibit less nonspecific priming than younger subjects in *absolute* terms, if priming is expressed as a *proportional* increase over the baseline completion, the elderly actually exhibit slightly more nonspecific priming than do young subjects (old/young differences in the voice-specific component of priming are seen with both absolute and proportional measures). The difference between the two measures of nonspecific priming arises because the baseline levels of stem completion are lower in old than in young subjects. Evidence considered later in this article suggests that nonspecific priming is not impaired in older adults.

What does the absence of voice-specific priming in the elderly tell us about underlying processes and mechanisms? Before we can address this question directly, several potential difficulties with the data from Experiment 1 need to be considered. First, it is conceivable that the voice-specific component of priming that we observed in young subjects is not an unintentional priming effect, but instead reflects the use of intentional retrieval strategies. That is, young subjects may have converted the nominally implicit stem-completion test into a functionally explicit cued-recall test, thereby making use of explicit memory abilities that are less available to older adults. This kind of issue has arisen in experiments discussed earlier that purported to show visual priming deficits in elderly adults (e.g. Davis et al., 1990; Hultsch et al., 1991; for discussion see Graf, 1990; Light, 1991; Schacter et al., 1993).

We think that the design and results of our experiment allow us to rule out this possibility. The key observation is that the magnitude of priming for young subjects was virtually identical after meaning and clarity encoding tasks, whereas explicit recall was much higher after the meaning task than the clarity task. If young subjects had indeed been engaging in intentional, explicit retrieval during the stem-completion test, we should have observed more priming in the meaning encoding condition than in the clarity encoding condition. Similarly, if the voice effect were attributable to intentional retrieval, then it should have been observed and even enhanced on the cued-recall test. But neither of these effects occurred: type of encoding task affected cued recall but not priming whereas voice change affected priming (in young subjects) and not cued recall. Thus, our data satisfy the *retrieval intentionality criterion* that has been put forward by Schacter et al (1989); when identical physical cues are used on implicit and explicit tests, and an experimental manipulation affects the two tasks differently, the possibility that the implicit test was contaminated by intentional retrieval can be discounted (for further discussion, see Bowers & Schacter, 1990; Roediger et al., 1992; Roediger & McDermott, 1993; Schacter et al., 1989).

Another possibility that must be considered, however, involves the possible contribution of age-related hearing loss to the observed pattern of results. It is well known that hearing impairment is frequently observed in older adults (e.g. Marshall, 1981; Olsho, Harkins, & Lenhardt, 1985). And, indeed, we observed that older adults misperceived significantly more stems on the completion test than did young subjects. We attempted to screen for gross hearing impairment in the elderly by requiring 80% or better performance on the auditory repetition subtest of the Boston Diagnostic Aphasia Examination. However, this criterion may not have been strict enough to pick up all cases of age-related hearing impairment, so it is still possible that the absence of voice-specific priming in the elderly is attributable to sensory hearing loss. For example, the existence of undetected hearing impairment in some subset of the old subjects might have prevented them from establishing a sufficiently rich acoustic representation of the target items to support voice-specific priming, or might have prevented them from extracting the necessary acoustic information from the test cues. The fact that elderly adults provided fewer target completions to stems representing nonstudied words in the baseline condition—even after excluding misperceived stems—suggests that the elderly might have been processing the stems differently from the young, perhaps because of hearing difficulties. Experiment 2 examined this possibility.

EXPERIMENT 2

We addressed the possible role of hearing loss in two different ways. First, we screened all subjects with pure-tone audiometry and eliminated those whose performance fell in the impaired range. Second, we increased the intensity of the auditory stimuli in order to promote acoustic processing of target items.

Method

Subjects. Twenty-four elderly subjects participated in this experiment. They were recruited in the same manner as subjects in Experiment 1 and the inclusion criteria for participation in the experiment were the same, except that subjects had to pass the hearing test.

Subjects had a mean age of 68.4 years (SD = 4.87; range = 61–78), and they had on average 16.17 years of education (SD = 2.71; range 10–20). Subjects achieved a mean score of 62.25 (SD = 6.15; range = 48–70) on the WAIS–R vocabulary subtest, and a mean score of 24.04 (SD = 2.20; range = 20–28) on the information subtest.

The hearing test followed standard procedures of pure tone audiometry, and was conducted by an experimenter (D.O.) with a Lucas-Grayson GSI 16 audiometer. We included in the experiment only those subjects who passed the American National Standards Institute criterion of normal elderly hearing, which is defined as being able to hear pure tones at a threshold of 35dB HL from 125 to 2000Hz, and 50dB HL from 3000 to 6000Hz. In order to find 24 participants who met these standards, it was necessary to test 39 subjects and eliminate 15 individuals who fell below the criterion.

Materials, Design and Procedure. Materials, design, and procedure were identical to Experiment 1, except that: the auditory tapes were recorded at two recording levels louder than the original tapes to help subjects hear the stimuli; and because previous research has revealed identical levels of auditory priming after semantic and nonsemantic encoding tasks, only the nonsemantic encoding task was used.

Results and Discussion

As in Experiment 1, the completion data were initially analysed both unconditionalised and conditionalised on correct stem perception. The pattern of results was identical in the two analyses. To maintain consistency with Experiment 1, we report results from the conditionalised analysis. Elderly adults misperceived 0.29 of stems representing nonstudied items and 0.23 of stems representing studied items; within the studied items, they misperceived about the same number of stems in the same- and different-voice conditions.

Proportions of target completions in the various experimental conditions are presented in Table 3. It is clear from the Table that Experiment 2 has yielded a nearly perfect replication of elderly subjects' completion data in the clarity encoding condition of Experiment 1: there was evidence of priming in both the same- and different-voice conditions, $ts(23) = 4.47$ and 4.55, respectively, $P < 0.001$, and virtually no difference between the two conditions, $t<1$. The cued recall data (Table 3) also provide a close replication of the corresponding data from Experiment 1: recall levels were generally low and there was no difference between same and different voice conditions, $t<1$.

These results indicate that the failure in Experiment 1 to observe voice-change effects in elderly adults is not likely to be attributable to undetected hearing impairments. Even when we excluded subjects with significant hearing impairment, and increased the decibel level of the stimuli, we did not observe voice-specific priming. Moreover, subjects in Experiment 2 actually misperceived test stems somewhat *more* frequently than did elderly subjects in Experiment 1. If hearing loss had indeed played a causal role in processing of the stems, we would expect that excluding subjects with hearing impairment, and increasing the decibel level of the stems, would reduce the incidence of stem misperception. Furthermore, the fact that we excluded a large proportion of elderly subjects from participating in Experiment 2 because they showed evidence of hearing impairment—over 40% of candidates—indicates that the hearing abilities of subjects in Experiment 2 were considerably higher than those of subjects in Experiment 1. Yet the two groups of subjects showed virtually identical patterns of stem perception and completion. These considerations suggest that stem misperceptions and the absence of voice-change effects in the elderly are not attributable to hearing loss.

An alternative possibility is suggested by evidence of abnormal temporal processing in the ageing auditory system (McCroskey & Kasten, 1982). Various kinds of data indicate that elderly adults have special difficulties processing rapid acoustic sequences (e.g. Newman & Spitzer, 1983; Robin & Royer, 1989)

TABLE 3
Priming Scores, Corrected Recall Scores, and the Proportion of Nonstudied Target Words Reported on the Auditory Stem-Completion and Cued-Recall Tests in Experiment 2

	Speaker's Voice		
Type of Test	*S*	*D*	*NS*
Stem-Completion	0.14	0.15	0.09
Cued-Recall	0.17	0.15	0.05

S = Same, D = Different, NS = Nonstudied. All subjects were older adults.

and time-compressed speech (e.g. Sticht & Gray, 1969). Moreover, Elliot, Hammer, and Evan (1987) report that older adults had special difficulties extracting information from auditory word beginnings in a gating paradigm that employed target materials similar to the stems that we used in Experiments 1 and 2 (see also Wingfield, Aberdeen, & Stein, 1991). These considerations, together with the age-related deficit in stem perception that we observed, suggest that elderly adults may have had difficulty processing the test stems because of their restricted temporal duration. Accordingly, they may not have been able to extract the kind of acoustic information from test stems that provides access to the stored voice information that supports voice-specific priming. It is thus conceivable that elderly adults would exhibit voice-specific priming on an implicit test other than stem completion, one that does not use artificially truncated bursts of speech. We examined this possibility in Experiment 3.

EXPERIMENT 3

In Experiment 3, we assessed auditory priming with an identification test in which studied and nonstudied words were low-pass filtered. A low-pass filter reduces the decibel level of a distribution of frequencies above a specified cut-off point. The filtering process generally preserves fundamental frequency information and prosodic contour information, and degrades higher-frequency information. Subjectively, filtered words sound somewhat muffled, as if they were spoken from the other side of a wall. We have documented voice-specific priming effects on the filter identification test in young subjects (Church & Schacter, 1994). If elderly adults failed to exhibit voice specificity in Experiments 1 and 2 because of difficulties in processing temporally truncated stems, then they should exhibit normal voice effects in this experiment, because low-pass filtering does not affect temporal properties of a word.

Method

Subjects. Twenty-four elderly adults participated in this experiment. They were recruited in the same manner as subjects in Experiment 1, and inclusion criteria were the same. All elderly subjects had their hearing tested in the manner described for Experiment 2, and they all met our criterion for normal hearing. Twenty-four young subjects, ranging in age from 17–25 years, also completed this experiment. They were recruited by sign-up sheets posted in the psychology department at Harvard University and were paid $5.00 for their participation in the experiment. The data from the young subjects are reported separately in Church and Schacter (1994).

Elderly subjects had a mean age of 66.79 years (SD = 4.46; range = 60–77), and they had on average 16.17 years of education (SD = 2.44; range = 12–20). They achieved a mean score of 59.29 (SD = 6.48; range = 43–68) on the WAIS–

R vocabulary subtest, and a mean score of 22.29 (SD = 3.79; range = 15–28) on the information subtest.

Materials. We used the same word lists described in Experiment 1. For the implicit test, the words were degraded with a low-pass filter, as described in previous experiments completed in our laboratory (for details, see Church & Schacter, 1994). After recording words on a Macintosh computer with a MacRecorder (sampling rate = 22k), each word was filtered with the low-pass filter function that is part of the SoundEdit program, and was passed through the filter three times. On each pass through the filter, the intensity of a distribution of frequencies above 2kHz is reduced by 20dB and the intensity of a distribution of frequencies between 1kHz and 2kHz is reduced between 5dB and 20dB.

Three male and three female speakers were recorded to yield two versions of each of the two study lists, the filter identification test, and the recognition test. Any word that was spoken by a male on one version of a tape was spoken by a female on the other, and vice versa, so that all words and speakers could be counterbalanced completely. The four study-list tapes each contained 24 words spoken clearly. The two filter identification tapes each included 48 degraded words, 24 that had been studied previously and 24 that had not been studied; the two recognition tapes each contained 48 words spoken clearly, 24 that had been studied and 24 that had not been studied (all of which had been presented in the filter identification test). On both the identification and recognition tasks, half of the words were presented in the same voice as on the study task and half of the words were presented in a different voice. All words were presented using a cassette deck and headphones.

Design and Procedure. The experiment used a mixed-factorial design. The between-subjects variable was age (young *vs* old), and the within-subjects variables were item type (studied *vs* nonstudied), speaker's voice (same *vs* different), and type of test (low-pass filter *vs* yes/no recognition). All aspects of experimental design and procedure were the same as in Experiment 1, except that the filter task replaced the stem-completion test and the recognition test replaced the cued-recall test. Subjects completed the tasks in the following order: 1. the clarity of enunciation encoding task; 2. the city-generation distractor task; 3. the implicit filter task; and 4. the explicit recognition task. For the filter task, subjects were told that they would hear a series of muffled words, that we were interested in their subjective perceptions of the words, and that they should respond by providing the first word that came to mind in response to the stimulus. For the recognition test, studied and nonstudied words were spoken clearly, and subjects were instructed to respond ''yes'' when they remembered the word from the study phase of the experiment, and 'no'' when they did not. On completion of the experiment all subjects were debriefed.

Results

Filter Identification. Table 4 presents the proportion of nonstudied words identified correctly on the low-pass filter task along with priming scores (i.e. proportion of studied words identified correctly minus proportion nonstudied words identified correctly) for both old and young subjects.

The elderly identified fewer nonstudied words (0.51) than did the young (0.59), $t(46)=2.22$, $P<0.05$. Both groups exhibited significant ($P<0.001$) priming effects in the same-voice condition, $ts(23)=4.96$ and 8.67, for old and young, respectively, and in the different-voice condition, $ts(23)=5.33$ and 4.18 for old and young, respectively. More importantly, however, the young exhibited significantly more priming in the same-voice condition (0.21) than in the different-voice condition, (0.13); $t(23)=2.42$, $P<0.05$, whereas the elderly showed identical priming scores (0.15) in the two conditions. An ANOVA revealed a marginally significant Subject Group × Speaker's Voice interaction, $F(1,46)=325$, $MSe=0.013$, $P=0.078$. In the different-voice condition, however, the elderly exhibited about as much priming (0.15) as did young subjects (0.13).

Recognition Memory. Table 4 also shows the data from the explicit recognition test in terms of false-alarm rates to nonstudied items and corrected recognition scores (i.e. hits minus false alarms; hit rates can be computed by adding the corrected recognition scores to the false-alarm rates). Elderly adults exhibited a higher false-alarm rate and lower hit rate than did young subjects. An ANOVA that was performed on the corrected recognition scores revealed a highly significant main effect of Age, $F(1,46)=18.53$, $MSE=0.093$, $P<0.0001$. Consistent with previous studies, there was no evidence of a voice-change effect in the corrected recognition scores of young subjects; corrected recognition in the same-voice condition (0.52) was actually slightly lower than was corrected recognition in the different-voice condition (0.56). Surprisingly, however, older

TABLE 4
Priming Scores and Proportion of Nonstudied Target Words Reported on the Auditory Identification Test, and Corrected Recognition Scores and False Alarm Rates on the Auditory Recognition Test as a Function of Age and Speaker's Voice in Experiment 3

	Old			*Young*		
	Speaker's Voice			*Speaker's Voice*		
Type of Test	*S*	*D*	*NS*	*S*	*D*	*NS*
Identification	0.15	0.15	0.51	0.21	0.13	0.59
Recognition	0.31	0.19	0.42	0.52	0.56	0.24

S = Same, D = Different, NS = Nonstudied subjects showed higher corrected recognition scores in the same-voice condition (0.31) than in the different-voice condition (0.19). The ANOVA showed a nonsignificant main effect of Speaker's Voice, $F<1$, together with a marginally significant Subject Group × Speaker's Voice interaction, $F(1,46)=3.57$, $MSe=0.016$, $P=0.065$. T-tests showed that the "negative" voice effect in young subjects was not significant, $t(23)<1$, nor was the apparent positive voice effect in elderly subjects, $t(23)=1.65$, two-tailed $P=0.113$.

Discussion

The results from the filter identification test replicate and extend the findings of the stem-completion test: young subjects exhibited voice-specific priming whereas old subjects did not. These data are not consistent with the idea that older adults' failure to exhibit voice-specific priming on the stem-completion test in Experiments 1 and 2 is specifically attributable to the brief duration of auditory stems, because low-pass filtering does not degrade temporal information.

As with the stem-completion task, it is always possible to argue that the voice-specific component of priming reflects the use of intentional, explicit strategies by young subjects that are less available to the elderly. But just as with stem-completion priming, there are empirical grounds for rejecting this interpretation of filter identification priming. First, Church and Schacter (1994) have provided evidence that priming on the filter identification task is unaffected by semantic *vs* nonsemantic study manipulations that have large effects on explicit memory. Second, the results of the present experiment indicate that when young subjects are asked to engage in explicit retrieval on the recognition test, they do not exhibit voice-specific effects. Taken together, these considerations make it highly unlikely that voice-specific priming is an artifact produced by intentional retrieval in young subjects.

The fact that young subjects showed similar levels of recognition memory in same- and different-voice conditions replicates previous observations in our laboratory (Church & Schacter, 1994; Schacter & Church, 1992). In contrast, the elderly exhibited a trend towards a voice-change effect on the recognition test. Although the effect was not significant, it raises the possibility that the elderly can exhibit voice-specific memory on an appropriate test—perhaps when words are spoken clearly, as on our recognition task.

The foregoing considerations raise the possibility that the elderly failed to exhibit voice-specific priming on the filter test because they had difficulties processing the degraded stimuli. We noted earlier that the filter identification test, unlike the stem-completion test, does not degrade the temporal properties of a word. Nevertheless, a low-pass filter does degrade frequency information in the target words, and older adults exhibited significantly, though not dramatically, lower levels of baseline identification performance than did young subjects. Indeed, there is independent evidence that older adults can have difficulties processing frequency-degraded speech information, although such deficits are not always observed (see Marshall, 1981). Accordingly, it is possible that older adults were not as able as young subjects to extract the information from the filtered signal that is necessary for accessing stored voice information. One implication of this suggestion is that older adults would exhibit voice-specific priming under conditions in which it is easier to identify filtered words—that is, when their baseline level of identification performance is substantially higher than in Experiment 3. We examined this possibility in Experiment 4.

EXPERIMENT 4

We attempted to enhance elderly adults' ability to extract information from the test stimulus, and to raise their baseline levels of filter identification performance, by presenting them with a less degraded stimulus than we used in Experiment 3. Specifically, instead of degrading target words by putting them through the low-pass filter three times, with each pass through the filter eliminating more and more high-frequency information from the signal, we low-pass filtered them only twice. Pilot data indicated that this manipulation made it easier for elderly subjects to identify the filtered words, as reflected by higher levels of baseline identification performance than were observed in Experiment 3. If the absence of voice-specific priming in the elderly is attributable to low levels of baseline performance, then we should observe voice-specific effects when baseline levels of identification performance are increased. We also wanted to determine whether the substantial but non-significant trend for voice-specific recognition that the elderly exhibited in Experiment 3 constitutes a reliable and replicable phenomenon.

Method

Subjects. Twenty four elderly subjects with age-normal hearing participated in the experiment. They were recruited in the same manner as subjects in previous experiments. The subjects had a mean age of 67.46 years (SD = 4.15; range = 60–76), and they had on average 15.54 years of education (SD = 2.13; range = 12–20). Subjects achieved a mean score of 58.44 (SD = 7.22; range = 36–69) on the WAIS-R vocabulary subtest, and a mean score of 23.42 (SD = 3.53; range = 13–28) on the information subtest.

Materials, Design, and Procedure. All aspects of Experiment 4 were identical to Experiment 3, except that on the identification test, target words were low-pass filtered twice instead of three times.

Results and Discussion

Table 5 indicates that the filtering manipulation had the intended effect of raising baseline levels of identification performance, with elderly subjects now identifying 0.72 of nonstudied words. As in previous experiments, exposure to words on the study list produced a significant priming effect in both the same-voice condition, $t(23)=2.62$, $P<0.02$, and the different-voice condition, $t(23)=3.72$, $P<0.01$. Nevertheless, no evidence for voice-specific priming was observed: priming scores were nonsignificantly higher in the different-voice condition (0.11) than in the same-voice condition (0.08), $t(23)<1$. On the recognition test, we observed only a weak trend for voice-specific memory. Corrected recognition scores were slightly higher in the same-voice condition (0.22) than in the different-voice condition (0.19), but the effect did not approach significance, $t(23)<1$.

Experiment 4 thus provides no evidence to support the view that absence of voice-specific priming in the elderly is attributable to low levels of baseline identification performance. It could be argued, or course, that our manipulation for raising baseline levels of performance was in some sense too effective: older adults in Experiment 4 actually had higher levels of baseline performance than young subjects in Experiment 3, perhaps so high that priming scores in the same-voice condition were artificially depressed by a ceiling effect. However, there are two difficulties with such a suggestion. First, identification rate for studied items was approximately 0.80, well below absolute ceiling levels. Second, there was a numerical trend for more priming in the different-voice condition than in the same-voice condition. If a voice-specific priming effect was in fact being obscured by a ceiling effect, we should have observed at least a trend for more priming in the same-voice condition than in the different-voice condition. But we did not.

TABLE 5
Priming Scores and Proportion of Nonstudied Target Words Reported in the Auditory Identification Test, and Corrected Recognition Scores and False Alarm Rates on the Auditory Recognition Test as a Function of Speaker's Voice in Experiment 4

	Speaker's Voice		
Type of Test	*S*	*D*	*NS*
Identification	0.08	0.11	0.72
Recognition	0.22	0.19	0.45

S = Same, D = Different, NS = Nonstudied. All subjects were older adults.

We also failed to observe significant voice-change effects on the recognition test, where words are spoken clearly. Thus, simply presenting words clearly is not sufficient to produce voice-specific effects in elderly adults. We have argued previously (Schacter & Church, 1992) that young subjects typically do not show voice specificity on recognition memory tests (although under certain conditions they can; e.g. Craik & Kirsner, 1974; Palmeri, Goldinger, & Pisoni, 1993) because they tend to rely on conceptual and contextual information, and not perceptual information, when making recognition judgements. Older adults depend less on conceptual and contextual information when making recognition judgements than do young subjects (see, for example, Dywan & Jacoby, 1990; Light, 1991; Parkin & Walter, 1992), but they may rely enough on such information to override any potential influences of voice information.

Although the lighter filtering used in Experiment 4 clearly improved the elderly subjects' ability to identify target words, it must be noted that the words still were significantly degraded. We have argued that hearing problems cannot account for the lack of voice-specific priming in the elderly, but it is possible that a subtle hearing deficit prevents them from extracting detailed acoustic information from *any* degraded stimulus. Such an impairment might eliminate voice-specific priming on completion and identification tests, where degraded stimuli are used.

In light of the foregoing considerations, it is important to point out that the older subjects who participated in Experiments 2–4 exhibited age-normal hearing. However, subjects who meet the criteria for age-normal hearing, although not hearing-impaired, still perform more poorly than young adults and are characterised by some loss of sensitivity to high frequencies. It is conceivable that these subtle problems might interfere with the expression of voice-specific priming on tests involving degraded stimuli.

We assessed this hypothesis in Experiment 5 by examining the performance of elderly subjects who exhibit normal young hearing—that is, older adults who perform indistinguishably from young subjects when tested with pure tone audiometry. If the absence of voice-specific priming on the filter identification test is attributable to the presence of subtle hearing deficits that interfere with processing degraded stimuli, then these subjects should show voice-specific priming effects.

EXPERIMENT 5

Method

Subjects Sixteen elderly subjects participated in the experiment. They were recruited in the same manner as subjects in previous experiments. Inclusion criteria for participation in the experiment remained the same, except that subjects had to exhibit normal young hearing. It was necessary to test 67 subjects in order to find 16 who met our criterion. The experimenter administered audiometric testing as described previously. Subjects were included in the experiment when they met the threshold of 25dB HL from 125 to 6000Hz, which is considered equivalent to young hearing (under 30 years of age) according to ANSI standards.

The subjects had a mean age of 63.88 years (SD = 4.89; range = 60–77), and they had on average 14.31 years of education (SD = 1.99; range = 12–18). Subjects achieved a mean score of 58.69 (SD = 7.67; range = 45–67) on the WAIS–R vocabulary subtest, and a mean score of 20.75 (SD = 4.37; range = 13–27) on the information subtest.

Materials, Design and Procedure. All aspects of materials, design, and procedure were identical to Experiment 3, where three passes through the filter were used to degrade items for the identification test.

Results and Discussion

Data from the filter identification test are presented in Table 6. The results are quite clear-cut: there was significant priming in both the same-voice condition, $t(15)=3.27$, $P<0.005$, and the different-voice condition, $t(15)=4.57$, $P<0.001$, and no difference between conditions; in fact, there was slightly more priming in the different-voice condition (0.17) than in the same-voice condition (0.15), $t<1$. Thus, elderly adults with normal young hearing showed the same pattern as did older subjects with age-normal hearing. Indeed, there was a striking quantitative similarity in the performance of the two groups. Subjects with age-normal hearing, who were tested in Experiment 3 under conditions identical to those used in the present experiment, exhibited nearly identical baseline levels of identification performance to subjects with young normal hearing (0.51 *vs* 0.53). This observation suggests that whatever subtle hearing deficits may be present in

TABLE 6
Priming Scores and Proportion of Nonstudied Target Words Reported in the Auditory Identification Test, and Corrected Recognition Scores and False Alarm Rates on the Auditory Recognition Test as a Function of Speaker's Voice in Experiment 5

	Speaker's Voice		
Type of Test	*S*	*D*	*NS*
Identification	0.15	0.17	0.53
Recognition	0.29	0.30	0.43

S = Same, D = Different, NS = Nonstudied. All subjects were older adults.

the subjects with age-normal hearing do not play a significant role in filter identification performance.

Table 6 indicates that there was no evidence for voice-specific recognition in the group with young normal hearing: corrected recognition scores were nearly identical in the same-voice condition (0.29) and the different-voice condition (0.30). Thus, we have replicated the results from Experiment 4 and provided further evidence that the trend for voice-specific recognition observed in Experiment 3 is not reliable. The most straightforward interpretation of the recognition data is that neither older nor younger adults show robust evidence of voice-specific recognition under the conditions of our experiments.

GENERAL DISCUSSION

The overall pattern of results from our five experiments is clear and consistent. On both auditory stem-completion and filter identification tests, elderly adults showed significant priming in both the same-voice and different-voice conditions. However, they failed to exhibit more priming in the same-voice condition than in the different-voice condition in each of the five experiments. Young subjects, by contrast, exhibited more priming in the same- than in the different-voice condition on both stem-completion (Experiment 1) and filter identification (Experiment 3) tasks. We have replicated and extended this finding of voice-specific priming with young subjects in various other experimental conditions (Church & Schacter, 1994; Schacter & Church, 1992).

The first issue to be addressed concerns whether the auditory priming deficit observed in the elderly involves only the voice-specific component, or whether it includes the nonspecific component as well. In each of the five experiments, elderly adults exhibited significant priming in the different-voice condition, in sharp contrast to their failure to exhibit voice-specific priming in any of these experiments. On the filter identification test (Experiment 3), old and young subjects showed essentially identical levels of nonspecific priming in the different-voice condition; on the stem-completion test (Experiment 1), younger subjects showed more nonspecific priming than did older subjects with an absolute measure, but older adults showed more nonspecific priming with a proportional measure. Thus, it seems reasonable to conclude that the age-related priming deficit that we observed is restricted to the voice-specific component of auditory priming.

We have argued and provided evidence that the absence of voice-specific priming in the elderly cannot be attributed to sensory hearing loss; even older adults with normal young hearing exhibit no hint of a voice effect in filter identification performance. It must be acknowledged, however, that elderly adults are known to exhibit problems in speech recognition and identification that are not attributable to simple hearing loss, and that are not tapped by assessment with pure tone audiometry; such problems tend to be exacerbated when speech stimuli are degraded (for review, see Marshall, 1981; Wingfield & Stein, 1992). It is thus conceivable that the absence of voice-specific priming in our studies reflects a high-level auditory/speech processing deficit in older adults that is not detected by our audiometric assessment, or by our cut-off of 80% correct on the speech discrimination subtest from the Boston Diagnostic Aphasia Examination.

We cannot reject this possibility unequivocally, and we plan to evaluate it systematically in future research. Nevertheless, there are grounds for expressing doubt about the idea. First, older adults consistently exhibited entirely normal levels of priming in the different-voice condition of the filter identification test. If a speech processing deficit accounts for the absence of voice-specific priming, it seems reasonable to suppose that it would also produce impaired nonspecific priming. Second, even when baseline identification performance of the elderly was raised to a high level in Experiment 4, no trends for voice-specific priming were apparent.

Our results complement and extend the previous findings of Light et al. (1992) that elderly adults exhibit intact auditory priming on an identification-in-noise test. The fact that the elderly exhibited robust and near-normal priming in our different-voice condition is consistent with Light et al.'s finding of intact modality-nonspecific priming in their elderly subjects—that is, the component of priming that transfers across different voices in our paradigm presumably overlaps considerably with the component of priming that transfers across modalities in Light et al.'s study. The fact that we failed to observe voice-specific priming in the elderly, coupled with Light et al.'s finding of normal modality-specific priming, underscores our previous suggestion that priming on the identification-in-noise test is characterised by *modality specificity* but not by *voice specificity*. Modality-specific priming on the identification-in-noise test may depend on the activation of relatively abstract auditory word forms that preserve information concerning the phonological structure of words, independently of a particular speaker's voice (e.g. Jackson & Morton, 1984). These same phonological word-forms might be activated by visual presentation of a word, albeit not as strongly as by auditory presentation. Alternatively, other mechanisms may be involved in cross-modal priming (for discussion, see Kirsner, Dunn, & Standen, 1989).

In any case, the critical point for the present purposes is that modality-specific priming effects on the identification-in-noise test do not appear to reflect implicit memory for the perceptual context of an auditory presentation. Voice-specific priming, by contrast, does reflect retention of detailed acoustic attributes of an auditory presentation. Because elderly adults exhibit modality-specific priming, but have thus far failed to exhibit voice-specific priming, we think it is necessary to amend Light et al.'s suggestion that elderly adults can show access to contextual information when tested indirectly.

How, then, are we to think about the pattern of results that we have obtained? In previous papers we have argued that priming on auditory identification and completion tests depends heavily on a presemantic perceptual representation system (PRS) that can function independently of the episodic system that underlies explicit recall and recognition (Schacter, 1992, 1994; Schacter & Church, 1992). The PRS is composed of various cortically-based, modality-specific subsystems that process and represent information about the form and structure, but not the meaning and associative properties, of words and objects (Schacter, 1990; Tulving & Schacter, 1990). PRS can operate independently of the episodic system that underlies explicit recall and recognition performance, a system that depends on the integrity of limbic/diencephalic structures (Squire, 1992). Thus, we and others have argued that perceptual priming is typically spared in amnesic patients with limbic/diencephalic lesions because such lesions spare the PRS or a similar system (cf Moscovitch, 1994; Schacter, 1994; Squire, 1994). With respect to auditory priming in particular, we have suggested that two PRS subsystems may be involved: one represents the phonological form of words, the other handles prosodic or acoustic information, including speaker's voice (see Schacter, 1994, for discussion).

Recent observations concerning auditory priming in amnesic patients have led us tò suggest an additional idea that has implications for thinking about the performance of elderly adults. We found that amnesics exhibited normal auditory priming on the identification-in-noise test and, as in control subjects, the magnitude of priming was unaffected by study-to-test changes in speaker's voice (Schacter, Church, & Treadwell, 1994). However, we have also observed that amnesic patients—like elderly adults—do not exhibit voice-specific priming on the filter identification test, whereas matched control subjects do (Schacter, Church, & Bolton, in press). These observations have led us to suggest that in order to exhibit voice-specific priming on the filter identification test it may be necessary to bind together, at the time of study, phonological information concerning a spoken word-form and acoustic information concerning the voice of the speaker who enunciates the word. Moreover, such binding may require the participation of limbic/diencephalic structures that are damaged in amnesic patients. Accordingly, voice-specific priming may require an interaction between the PRS and the episodic system (see Schacter, 1994, for further elaboration).

The same sort of analysis could apply to elderly adults—that is, voice-specific priming may depend on the binding operations of an episodic system that is impaired by ageing. Thus, the specific link between word and voice that is necessary to support voice-specific priming may not be established strongly enough at the time of encoding to influence subsequent implicit task performance, although word and voice information are each encoded separately. It is interesting to consider these ideas in relation to Kausler and Puckett's (1981) research concerning explicit recognition of speaker's gender.

They found that younger subjects showed similar levels of above-chance speaker-recognition accuracy following incidental encoding of voice information (subjects were told to remember target sentences, but were not told to remember the speaker) and intentional encoding (subjects were instructed to remember both sentences and speakers). Elderly adults, by contrast, exhibited above-chance levels of speaker recognition only in the intentional encoding condition. In addition, above-chance levels of speaker recognition were accompanied by correspondingly lower levels of sentence recall in the elderly, but this trade-off was not observed in the young. These data are consistent with the idea that older adults are less able to bind together voice information and target information than are young subjects.

There are, of course, important differences between Kausler and Puckett's results on speaker recognition and our data concerning voice-specific priming. In addition to the explicit *vs* implicit test difference, results from several experiments indicate that speaker recognition is sensitive to encoding task manipulations and appears to be based on semantic or conceptual information (e.g. Geiselman & Bellezza, 1976; Kausler & Puckett, 1981), whereas voice-specific priming is insensitive to encoding task manipulations and does not involve semantic or conceptual information (Church & Schacter, 1994; Schacter & Church, 1992; Schacter, McGlynn, Milberg, & Church, 1993). Nevertheless, it may be worth contemplating the idea that a binding deficit underlies the age-related impairments that have been observed in both implicit and explicit tests of speaker's voice.

Of course, alternative hypotheses must also be considered. For instance, elderly adults may simply fail to encode a sufficiently rich acoustic representation to support voice-specific priming, or they may encode all the necessary information but fail to express it under the test conditions that we have used. It is important to note in this regard that elderly adults can exhibit perceptual specificity in visual priming of familiar words. Gibson, Brooks, Friedman, and Yesavage (1993) recently reported that older adults, like young subjects, show more stem-completion priming when the typeface of target words is the same at study and test than when it differs (see also Kinoshita & Wayland, 1993). Interestingly, typeface-specific priming was observed only following an encoding task that required subjects to judge the number of syllables in a word; significant typeface effects were not obtained after other encoding tasks (cf Graf & Ryan, 1990). By contrast, when voice-specific priming occurs on completion and filter identification tasks in young subjects, it does not depend on encoding task; the magnitude of voice-change effects is similar across a range of encoding conditions (cf Church & Schacter, 1994; Schacter & Church, 1992). The fact that voice-specific priming seems to occur more automatically than typeface-specific priming may contribute significantly to the contrasting patterns of results from auditory and visual modalities in elderly subjects. Alternatively, it is possible that an encoding condition exists that would yield evidence of voice-specific priming in the elderly. Distinguishing among these and other alternatives constitutes a necessary next step in attempting to understand the age-related priming deficit that we have documented.

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