

# Auditory Priming: Implicit and Explicit Memory for Words and Voices

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Five experiments explore priming effects on auditory identification and completion tasks as a function of semantic and nonsemantic encoding tasks and whether speaker's voice is same or different at study and test. Auditory priming was either unaffected by the study task manipulation (Experiments 2, 4, and 5) or was less affected than was explicit memory (Experiments 1 and 3). Study-to-test changes of speaker's voice had nonsignificant effects on priming when white noise masked target items on the identification test (Experiments 1 and 2) or the stem-completion test (Experiment 5). However, significant voice change effects were observed on priming of completion performance when stems were spoken clearly (Experiments 3 and 4). Results are consistent with the idea that a presemantic auditory perceptual representation system plays an important role in the observed priming. Alternative explanations of the presence or absence of voice change effects under different task conditions are considered.

*Explicit memory* and *implicit memory* are descriptive terms that refer to different ways in which effects of prior experience can be expressed (Graf & Schacter, 1985; Schacter, 1987). Explicit memory entails conscious recollection of previously studied information, as assessed by recall and recognition tasks. Implicit memory, by contrast, involves facilitations of task performance, often referred to as direct or repetition priming, that are produced by information acquired during a study episode without intentional or conscious recollection of that episode. A great deal of recent research and theorizing has focused on the relation between explicit and implicit memory, sparked largely by demonstrations of dissociations between explicit and implicit memory in both normal subjects and amnesic patients (for reviews, see Richardson-Klavehn & Bjork, 1988; Roediger, 1990; Schacter, 1987; Schacter, Chiu, & Ochsner, in press; and Shimamura, 1986).

Research concerning implicit memory has focused almost exclusively on tests involving visual processing. Thus, for example, the most frequently used implicit tasks—such as word identification (e.g., Graf & Ryan, 1990; Jacoby & Dallas, 1981), fragment and stem completion (e.g., Graf & Mandler, 1984; Hayman & Tulving, 1989; Roediger & Blaxton, 1987; Schacter & Graf, 1989; Tulving, Schacter, & Stark, 1982), and lexical decision (e.g., Moscovitch, 1982; Rueckl, 1990; Scarborough, Gerard, & Cortese, 1979)—involve visual processing of words or nonwords. Similarly, tasks such as picture completion (e.g., Jacoby, Baker, & Brooks, 1989; Snodgrass, 1989), picture naming (e.g., Bartram, 1974; Mitchell &

Brown, 1988), object decision (Kroll & Potter, 1984; Schacter, Cooper, & Delaney, 1990), and pattern completion and identification (e.g., Gabrieli, Milberg, Keane, & Corkin, 1990; Musen & Treisman, 1990) involve visual processing of pictures, objects, and patterns. Moreover, most theoretical accounts of implicit memory phenomena are based to a large extent on data from visual tasks and typically entail hypotheses about the characteristics of visually based processes or systems (cf. Jacoby, 1983; Kirsner, Dunn, & Standen, 1989; Roediger, 1990; Schacter, 1990; Squire, 1987; Tulving & Schacter, 1990).

By contrast, relatively little research has explored implicit memory in the auditory domain. Several studies have demonstrated repetition priming effects on auditory-word identification and sentence-identification tasks, in which target stimuli are masked in noise and subjects attempt to identify previously studied and nonstudied items (Ellis, 1982; Franks, Plybon, & Auble, 1982; Jackson & Morton, 1984; Kempley & Morton, 1982) or make subjective ratings of noise levels (Jacoby, Allan, Collins, & Larwill, 1988). Priming has also been shown on an auditory stem-completion task (Bassili, Smith, & MacLeod, 1989; McClelland & Pring, 1991) in which subjects provide the first word that comes to mind in response to spoken word stems that represent previously studied words or nonstudied words. However, little is known about the nature of priming effects on these tasks, and there have been few detailed proposals about the kinds of processes and systems that subservise implicit memory in the auditory domain. A number of other experiments have examined indirect or phonological priming effects on auditory identification and lexical decision tasks under conditions in which there is virtually no delay (e.g., 50 ms to 500 ms) between the appearance of a prime and a target (cf. Goldinger, Luce, & Pisoni, 1989; Jakimik, Cole, & Rudnicky, 1985; Slowiaczek, Nusbaum, & Pisoni, 1987; Slowiaczek & Pisoni, 1986). Although these studies have attempted to test theoretical models of spoken word recognition (e.g., Klatt, 1980; Marslen-Wilson & Welsh, 1978; Morton, 1979), the type of priming that they

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have investigated is extremely short-lived, sometimes dissipating within 500 ms (Goldinger et al., 1989). Therefore, it seems unlikely that this kind of priming is based on the same mechanisms that subserve repetition priming effects that persist across numerous items and across retention intervals of at least several minutes. Short-term priming effects will not be considered further in the present article.

The major purposes of this article are to elucidate experimentally several important properties of implicit memory in the auditory domain and to suggest a theoretical framework for thinking about relevant phenomena. Our approach to the investigation of auditory implicit memory is shaped by a framework developed in several recent articles (e.g., Schacter, 1990, 1992; Schacter, Cooper et al., 1990; Schacter, Rapcsak, Rubens, Tharan, & Laguna, 1990; Tulving & Schacter, 1990). The basic idea is that implicit memory effects observed on such data-driven tests as perceptual identification, word completion, and object decision depend to a large extent on a presemantic perceptual representation system (PRS). PRS is composed of a number of subsystems that process information about the form and structure, but not the meaning and associative properties, of words, objects, and other types of stimuli. The empirical motivation for postulating that priming is driven by perceptual systems is provided by some key characteristics of priming on data-driven implicit tasks. Priming does not require semantic or elaborative study processing; it shows a large degree of modality specificity and is often sensitive to within-modality changes of surface feature information between study and test (for a review and discussion, see Kirsner et al., 1989; Richardson-Klavehn & Bjork, 1988; Roediger & Blaxton, 1987; Roediger, Weldon, & Challis, 1989; and Schacter, 1990).

Independent evidence for the existence of PRS subsystems is provided by an entirely separate line of neuropsychological research on patients with reading and object processing deficits (see Schacter, 1990, 1992). These studies have shown that patients who have severe impairments in gaining access to semantic and associative knowledge of words or visual objects can nevertheless show relatively intact access to knowledge of the visual form and structure of the same words or objects (e.g., in the lexical domain, see Funnell, 1983; Sartori, Masterson, & Job, 1987; and Schwartz, Saffran, & Marin, 1980; in the object domain, see Humphreys & Riddoch, 1987; Warrington, 1982; and Warrington & Taylor, 1978).

Although the PRS framework has thus far focused on visually based subsystems, neuropsychological research suggests the existence of a form versus semantic dissociation within the auditory domain analogous to those observed within the visual domain. Specifically, a number of studies have described patients who are able to repeat spoken words but do not understand them. In cases of *word meaning deafness* (e.g., Ellis, 1982; Kohn & Friedman, 1986), patients can exhibit access to the meaning of the words through other modalities, as indicated by their normal reading comprehension and use of words in spontaneous speech. There is also some evidence that such patients can write words to dictation as well as repeat them, thereby suggesting that they can gain access to stored auditory word-form representations (Ellis, 1982; Ellis & Young, 1988). Thus, it has been suggested that

these patients' deficits are produced by a disconnection between a normally functioning system that handles acoustic and phonological properties of spoken words and a normally functioning semantic system. In cases of *transcortical sensory aphasia*, spared repetition and writing-to-dictation, together with poor comprehension of spoken words, are typically observed in conjunction with poor comprehension of written words (e.g., Coslett, Roeltgen, Rothi, & Heilman, 1987; Kertesz, Sheppard, & MacKenzie, 1982), thus suggesting preservation of an auditory system with damage to the semantic system itself.

In contrast to the foregoing, other patients have exhibited a form of auditory agnosia termed *pure word deafness* (e.g., Shoumaker, Ajax, & Schenkenberg, 1977; Metz-Lutz & Dahl, 1984; Caramazza, Berndt, & Basili, 1983). In pure word deafness, the patient is unable to repeat or understand auditorily presented words even though speech production, reading, hearing, and the ability to recognize nonspeech sounds are preserved. This deficit can be interpreted as indicating the impairment of a system that specifically processes and represents the spoken forms of words.

The foregoing dissociations suggest the existence of a presemantic PRS subsystem that handles information about auditory word forms separately from semantic information (e.g., Ellis & Young, 1988). Therefore, according to the PRS framework, it ought to be possible to observe priming effects on auditory implicit memory tests that are in some respects similar to phenomena that have been documented on visual implicit tests (Schacter, 1992). Specifically, auditory priming should show a large degree of modality specificity, there should be relatively little influence of semantic versus nonsemantic encoding manipulations on the magnitude of the effect, and study-to-test changes of surface feature information within the auditory modality should, at least under some conditions, reduce the magnitude of priming.

Existing evidence regarding modality effects is consistent with an auditory PRS hypothesis, because it has been shown that study-to-test modality shifts reduce priming effects on auditory identification tasks (Ellis, 1982; Jackson & Morton, 1984) and stem-completion tasks (Bassili et al., 1989). In addition, experiments by McClelland and Pring (1991) suggest that processing of phonological information plays a major role in the cross-modal priming effects that have been observed on the auditory stem-completion task. They found that cross-modal priming from visual presentation of a word was largest in study conditions that maximized acoustic and phonological processing (e.g., naming a word aloud) and smallest in study conditions that minimized acoustic and phonological processing (e.g., silent reading with articulatory suppression).

In contrast to the foregoing, no published studies have compared the effects of semantic and nonsemantic encoding on auditory priming, although this type of manipulation has been studied extensively within the visual domain (e.g., Bowers & Schacter, 1990; Graf & Mandler, 1984; Graf, Squire, & Mandler, 1984; Jacoby & Dallas, 1981; Schacter & Graf, 1986; Schacter & McGlynn, 1989). Investigation of this issue is particularly relevant to the idea that a form-based system subserves auditory priming: If the idea is correct, then a semantic versus nonsemantic encoding manipulation should

have little or no effect on auditory priming in contrast to large effects on auditory explicit memory. This predicted dissociation is also relevant to a more general observation about previous studies of auditory priming on identification and completion tasks: None have produced dissociations between priming and explicit memory, so it is not clear whether or to what extent apparent auditory priming effects may be attributable to, or contaminated by, explicit memory strategies (e.g., Bowers & Schacter, 1990; Schacter, Bowers, & Booker, 1989). Accordingly, we examined whether semantic and nonsemantic encoding tasks produce dissociable effects on implicit and explicit auditory tests with the dual purposes of evaluating the idea that a presemantic system subserves auditory priming and assessing whether apparent auditory priming effects are partly or entirely attributable to explicit memory.

We also examined whether auditory priming is sensitive to study-to-test changes in the surface features of target items. It has been argued that PRS subsystems can encode highly specific information about the form of words and objects (Schacter, 1990; Tulving & Schacter, 1990), thereby suggesting that study-to-test changes in surface feature information should affect priming, as has been observed in many studies of visual word priming. Relevant evidence in the auditory domain has been provided by Jackson and Morton (1984), who studied the effects of voice changes between study and test on priming of auditory-word identification. Subjects heard a list of target words spoken in either a male voice or female voice and then attempted to identify words that were spoken in the female voice masked in white noise. Jackson and Morton found that the magnitude of priming was indistinguishable in same and different voice conditions, and they concluded that auditory priming is based on the activation of modality-specific logogens that are indifferent to the specific form of a spoken word.

A recent study by Graf and Ryan (1990) on visual word priming suggests that acceptance of this conclusion may be premature. Graf and Ryan found that study-to-test changes in a word's typefont reduce the magnitude of priming on a word identification test only when subjects perform a study task that requires specific encoding of visual form information (i.e., rating the readability of the word). No effects of study-to-test changes in typefont were observed after a semantic encoding task. The relevance of these findings to the absence of voice change effects on auditory priming is straightforward: Jackson and Morton's (1984) subjects performed a semantic encoding task (categorizing the referents of target words as living or nonliving). In light of the Graf and Ryan results, it seems reasonable to hypothesize that voice change effects on auditory-word identification might be observed after an encoding task that focuses subjects on acoustic properties of a speaker's voice. We examined this possibility in the following experiments.

### Experiment 1

The major purposes of Experiment 1 were twofold: first, to evaluate the prediction that auditory priming is less affected than explicit memory by a semantic versus nonsemantic

encoding manipulation and, second, to assess whether study-to-test changes in the speaker's voice reduce priming after a study task that requires processing of voice characteristics. To accomplish these objectives, six speakers (three male and three female) presented subjects a list of words, and the subjects performed one of two study tasks: a semantic task in which they made category judgments about target words or a nonsemantic task in which the same words were presented, and subjects made pitch judgments about the voices. After a brief delay, during which subjects performed an unrelated distractor task, we asked subjects either to identify words embedded in white noise or to make explicit recognition judgments about the same words. In both tasks, half of the tested items had been presented previously, whereas half were new; half of the old words were spoken by the same voice as during the study task, and half were spoken by a different voice.

### Method

*Subjects.* Ninety-six introductory psychology students from the University of Arizona participated in Experiment 1 for course credit.

*Materials.* The target materials consisted of 48 familiar words. The words were divided into two sets of 24 (Set A and Set B) that were matched for frequency, concreteness, and length (Paivio, Yuille, & Madigan, 1968). Both sets contained 6 words from each of four semantic categories: (a) animals, (b) food or drinks, (c) places to live, and (d) occupations or roles. Six speakers, three male and three female, recorded the words. 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 the sex of the speaker. The words were recorded into a Macintosh computer using a MacRecorder; the computer generated the white noise and mixed it with the words. The computer played the words to subjects at volumes corresponding to normal conversational levels.

We recorded two versions of each of the 24-word study lists, with each word spoken in a male voice on one version and each word spoken in a female voice on the other version. The particular male or female voice assigned to each word was determined randomly. Any single subject would thus hear a study list word in either a male or a female voice, with male and female voices counterbalanced across subjects within each encoding condition. We recorded two versions of the auditory identification test and two versions of the recognition test in the same manner, with each of the 48 words recorded once in a male voice and once in a female voice (the same voices that were used on the study list). On the study list and recognition tapes, all words were spoken clearly, whereas on the auditory identification tapes all words were embedded in white noise.

We presented tapes during the study and the test using a cassette player and headphones. We provided a booklet for subjects to record all responses. The first page of the test booklet contained a 4-point number scale either for pitch (1 = *high*, 2 = *medium-high*, 3 = *medium-low*, and 4 = *low*) or for category (1 = *animals*, 2 = *food*, 3 = *places*, and 4 = *occupations*) and 24 numbered blanks for subjects to write their responses. The second page had 15 letters with blank areas for subjects to write the names of U.S. states for the distractor task, and the last page had 48 numbered blank lines for subjects to write their responses during the identification or recognition tests.

*Design and procedure.* The experiment used a  $2 \times 2 \times 2 \times 2$  factorial design. There were two between-subjects variables, encoding task (category vs. pitch) and type of test (identification vs. recognition), with 24 subjects in each of the four conditions defined by the orthogonal combination of these variables. The within-subjects variables were speaker's voice at study and test (same vs. different) and

item type (studied vs. nonstudied). The experiment was completely counterbalanced such that each item appeared equally often in the experimental conditions defined by the orthogonal combination of the four main variables. In addition, as noted previously, each item appeared equally often in a male and in a female voice, with speaker's gender counterbalanced across subjects on the study list and on both the identification and recognition tests.

We tested subjects individually. We presented words auditorily on a headphone and asked subjects either to rate the pitch of each speaker's voice on the 4-point scale or to indicate to which of the four categories each word belonged. We provided 5 s between words for making each judgment and recording each response. After the encoding task, we gave a distractor task in which we presented 15 letters of the alphabet and asked subjects to generate the name of a state that begins with each letter. Although there was no time limit to complete this task, most subjects required approximately 3 min to 4 min. Finally, we instructed subjects either to attempt to identify each of 48 degraded words or to make a yes or no recognition judgment about the same words spoken clearly. On both tests, half of the words had been presented during the encoding task, and half were new; half of the previously presented words were spoken in the same voice as during the encoding task, and half were spoken in a different voice. There were 7 s between words in both tasks for subjects to write their responses. After completing the task, we debriefed subjects concerning the nature of the experiment.

## Results

Table 1 presents the proportion of studied and nonstudied items reported on an auditory identification test as a function of encoding task (category vs. pitch) and speaker's voice (same vs. different). With respect to the latter manipulation, it is possible to subdivide further both the same voice condition (i.e., into male/male and female/female) and the different voice condition (i.e., into male/female and female/male). We performed a preliminary analysis of variance (ANOVA) to assess any possible effects of speaker's gender on either identification or recognition performance. No significant main effects or interactions with the independent variables were observed (all  $F_s < 2.47$ ). Accordingly, the voice data are collapsed across speaker's gender and are presented and analyzed in same voice and different voice conditions. This same pattern of results—no significant main effects of speaker's gender or interactions with other variables—was observed in all other experiments unless otherwise noted. Accordingly, these data, too, are presented and analyzed in same-voice and different-voice conditions.

The results in Table 1 indicate that priming was observed following both study tasks, that the magnitude of the effect

was somewhat greater following the category than the pitch task, and that there was a relatively small effect of changing speaker's voice between study and test. Statistical analysis supports this description of the results. To determine whether significant priming occurred, we initially compared the overall proportion of studied items identified correctly ( $M = .44$ ) and nonstudied items identified correctly ( $M = .28$ ). The difference between the two was highly significant,  $t(47) = 6.60$ ,  $p < .001$ . To assess effects of the experimental manipulations on priming, we performed a  $2 \times 2$  ANOVA in which the between-subjects variable was encoding task (category vs. pitch) and the within-subjects variable was speaker's voice (same vs. different). The dependent measure was a priming score that was computed by subtracting, in each condition, the proportion of identified nonstudied target words from the proportion of identified studied target words, thereby correcting for any between-groups differences in baseline performance. This analysis revealed a main effect of encoding task,  $F(1, 46) = 4.59$ ,  $p < .05$ ,  $MS_e = .023$ , together with a nonsignificant main effect of speaker's voice ( $F < 1$ ) and a nonsignificant Encoding Task  $\times$  Speaker's Voice interaction ( $F < 1$ ).

Table 2 displays the proportion of studied items given *yes* responses on the recognition test (i.e., hits) and the proportion of nonstudied items given *yes* responses (i.e., false alarms). Recognition performance was much higher in the category condition than in the pitch condition, whereas there were much smaller differences between the same and different voice conditions. We performed an ANOVA on corrected recognition scores that we computed by subtracting the proportion of false alarms from proportion of hits for each condition. The analysis revealed a highly significant effect of encoding task,  $F(1, 46) = 84.07$ ,  $p < .001$ ,  $MS_e = .048$ , a nonsignificant main effect of speaker's voice,  $F(1, 46) = 2.83$ ,  $MS_e = .012$ , and a nonsignificant Encoding Task  $\times$  Speaker's Voice interaction ( $F < 1$ ).

To compare priming and recognition more directly, we performed a combined ANOVA on the priming scores and corrected recognition scores, with encoding task and type of test as between-subjects variables and speaker's voice as a within-subjects variable. The critical outcome of the ANOVA was a significant Encoding Task  $\times$  Type of Test interaction,  $F(1, 92) = 40.28$ ,  $p < .001$ ,  $MS_e = .036$ , indicating that the category versus pitch manipulation had a significantly larger effect on recognition than on priming. No other interactions were significant, and the main effect of speaker's voice was also nonsignificant, all  $F_s < 2.28$ .

Table 1  
*Proportion of Target Words Reported on the Auditory Identification Test as a Function of Encoding Task (ET) and Speaker's Voice in Experiment 1*

ET	Speaker's voice		<i>M</i>	NS
	S	D		
Category	.51	.46	.49	.28
Pitch	.40	.38	.39	.27
<i>M</i>	.46	.42	.44	.28

Note. S = same; D = different; NS = nonstudied.

Table 2  
*Proportion of Hits and False Alarms (FA) on the Auditory Recognition Test as a Function of Encoding Task (ET) and Speaker's Voice in Experiment 1*

ET	Speaker's voice		<i>M</i>	FA
	S	D		
Category	.90	.86	.88	.06
Pitch	.72	.67	.69	.28
<i>M</i>	.81	.77	.79	.17

Note. S = same; D = different.

## Discussion

Experiment 1 revealed significant priming of auditory-word identification following both category and pitch encoding tasks, and it also indicated that the semantic versus nonsemantic encoding manipulation had greater effects on recognition memory than on priming. However, priming effects were larger following category than pitch encoding. By contrast, there were no significant effects of voice change on either priming or recognition memory.

Consider first the data on speaker's voice. Although there were trends in the direction of voice change effects on priming following both encoding tasks, they did not approach statistical significance. Although the failure to observe such effects in the category encoding condition is not entirely unexpected, inasmuch as it constitutes a replication and extension of Jackson and Morton's (1984) previous results, the absence of significant voice change effects in the pitch encoding condition is perhaps more surprising. As noted earlier, Graf and Ryan (1990) observed significant effects of study and test changes in surface features on priming of visual-word identification only when subjects performed a study task that required encoding of relevant surface features. Because we assume that the pitch encoding task focused subjects' attention on voice characteristics, our data constitute something of a puzzle.

To assess whether the absence of significant voice change effects reflects some sort of artifact associated with our procedure, we performed two additional analyses. First, we conducted an analysis of the fundamental frequencies of all speakers' voices to determine whether each of the three male and female speaker pairs that were used for the changed voice conditions differed significantly on this critical aspect of vocal pitch. If the fundamental frequencies of the paired male and female speakers were not significantly different, then the lack of voice change effects could be attributable to the physical similarity of the voices. We analyzed two words from each male and female pair by measuring fundamental frequency at 20 points within each word (all non-0 points), thus producing 40 observations per speaker and 80 observations for each male and female pair. The analysis showed that all of the female speakers had significantly ( $p < .01$ ) higher fundamental frequencies than the male speakers who were paired with them,  $t_s(78) = 7.69, 2.77,$  and  $11.99,$  for each of the three pairs, respectively.

A second, related analysis examined whether subjects could in fact process pitch information when we presented words in noise. If embedding words in white noise effectively eliminated subjects' ability to distinguish between high- and low-pitch voices (i.e., male vs. female), then the absence of voice change effects would not be surprising. To examine the issue, we tested 8 additional subjects by presenting words embedded in white noise, exactly as on the identification task and requiring subjects to perform the same pitch rating task that had been used at encoding. Each of the 8 subjects rated 48 masked words, including 8 words spoken by each speaker; for 4 of the subjects, the presented words were from Version 1 of the identification test, and for the other 4 subjects, the words presented were from Version 2 of the identification test. We performed analyses separately for each of the three male and

female speaker pairs, with a total of 64 observations per speaker (i.e., 8 subjects rating 8 words). The analysis confirmed that the pitch of each of the female voices was rated significantly ( $p < .001$ ) higher than the pitch of each of their paired male counterparts,  $t_s(126) = 12.09, 7.80,$  and  $27.07,$  for each of the three pairs, respectively. The results thus indicated that subjects can readily discriminate pitch differences between male and female voices even when noise is present.

The foregoing analyses suggest that the failure to observe voice change effects cannot be attributed to an inability to detect pitch differences between male and female voices. We consider another possibility later in the context of discussing data concerning the effects of the encoding manipulation.

The hypothesis that priming of auditory word identification is subserved by a presemantic PRS subsystem received qualified support at best from Experiment 1. On the one hand, the observed interaction between encoding task and type of test showed that priming was less affected than explicit memory by the semantic versus nonsemantic encoding manipulation, as predicted by the PRS hypothesis. On the other hand, there was a significant effect of type of encoding task on priming, a result that is not consistent with the notion that a presemantic system subserves priming of auditory word identification. Moreover, this main effect complicates interpretation of the Encoding Task  $\times$  Type of Test interaction: Because the encoding task affected performance on both implicit and explicit tests, the observed interaction might simply reflect scale differences on the two tasks. However, a careful examination of individual subjects' data revealed that virtually all of the difference between the priming scores observed in the two encoding conditions could be attributed to the abnormally high priming scores of 3 subjects in the semantic encoding condition. It is conceivable that these (and perhaps other) subjects discovered the relation between the identification test and encoding task and engaged in explicit retrieval strategies. To the extent that such explicit strategies were used, they would benefit subjects in the semantic encoding condition more than subjects in the nonsemantic condition, because explicit memory was higher in the former than in the latter condition. An experiment reported by Bowers and Schacter (1990) on visual word priming has provided evidence for precisely this sort of effect.

If these suggestions are correct, then it should be possible to eliminate the differences in the magnitude of priming that were observed following semantic and nonsemantic encoding tasks by altering task instructions in such a way as to discourage subjects from using explicit strategies. In Experiment 1, we instructed subjects to try to identify the correct word, and some subjects may have made use of explicit strategies to aid identification performance. In Experiment 2, we altered the instructions: We told subjects that we were interested in their subjective perception of words that are masked in noise and that they should respond on each trial with the first word that comes to mind. We reasoned that subjects would be unlikely to resort to explicit retrieval strategies with these task instructions.

This change in instructions might also bear on the finding that priming was not significantly affected by voice change in Experiment 1. Note that we also failed to observe significant

effects of voice change on recognition memory performance. If we assume for the moment that explicit memory is little affected or unaffected by voice change (at least under our task conditions; see General Discussion for elaboration of this point), then any contamination of implicit task performance by explicit retrieval strategies would work to obscure potential voice change effects. Accordingly, the use of test instructions that discourage the use of explicit strategies should provide more favorable conditions for observing effects of voice change on priming.

## Experiment 2

### Method

**Subjects.** Forty-eight University of Arizona introductory psychology students took part in Experiment 2. The subjects received class credit for their participation.

**Materials, procedures, and design.** The materials were identical to those used in Experiment 1. The design and procedure were also identical, with two exceptions. First, as noted earlier, we altered instructions: At the time of the identification task, we told subjects that the experiment was designed to examine their subjective impressions of auditory information that is degraded by noise, that their task was to write down the very first word that came to mind in response to each degraded stimulus, and that there was no right or wrong answer on the task. Second, type of test was changed from a between-subjects variable to a within-subjects variable. Because Experiment 1 had already demonstrated large effects of semantic versus nonsemantic encoding on recognition performance with type of test as a between-subjects factor, we gave all subjects the recognition test after they completed the identification test. We told subjects that all of the items on the recognition test had just appeared on the identification test, and we instructed subjects to say *yes* only when they remembered hearing an item during the study task and *no* when they did not remember hearing an item during the study task.

### Results

Consider first the priming data, presented in Table 3. We observed substantial priming effects following both encoding tasks. Most important, the magnitude of the priming scores (i.e., proportion of studied target items reported minus proportion of nonstudied target items reported) was virtually identical in the category encoding (.20) and pitch encoding (.21) conditions. There was no evidence of a voice change effect in the pitch condition, whereas there was a numerical trend for such an effect in the category condition.

Table 3  
*Proportion of Target Words Reported on the Auditory Identification Test as a Function of Encoding Task (ET) and Speaker's Voice in Experiment 2*

ET	Speaker's voice		<i>M</i>	NS
	S	D		
Category	.57	.50	.54	.34
Pitch	.50	.51	.51	.30
<i>M</i>	.54	.51	.53	.32

Note. S = same; D = different; NS = nonstudied.

A *t* test that compared the proportion of correct responses for studied and nonstudied items across conditions confirmed that significant priming was observed,  $t(47) = 5.92, p < .001$ . To assess the effects of the experimental manipulations, we performed a  $2 \times 2$  ANOVA in which priming scores were the dependent measure, encoding task was the between-subjects variable, and speaker's voice was the within-subjects variable. There were no main effects of encoding task,  $F < 1$ , or speaker's voice,  $F < 1$ . The Encoding Task  $\times$  Speaker's Voice interaction was also negligible ( $F < 1$ ). The failure to observe a significant Encoding Task  $\times$  Speaker's Voice interaction suggests that the apparent trend for a voice change effect in the category condition was not significant. Consistent with this observation, a *t* test that compared priming in the same and different voice conditions of the category task failed to reveal a significant difference,  $t(23) = 1.34$ . Not surprising, inspection of individual subjects' data from the same and different voice conditions in the category encoding group revealed a great deal of intersubject variability.

The recognition data, displayed in Table 4, differ sharply from the priming results with respect to the effects of the encoding task: Corrected recognition scores were much higher in the category condition (.64) than in the pitch condition (.30). By contrast, there were negligible effects of voice change on recognition accuracy. We performed an ANOVA on the corrected recognition scores and revealed a highly significant main effect of encoding task,  $F(1, 46) = 47.32, p < .001, MS_e = 2.81$ , no effect of speaker's voice,  $F < 1$ , and a nonsignificant interaction between these two variables,  $F < 1$ .

We performed a combined ANOVA on the priming scores and corrected recognition scores. The critical outcome of this analysis was a significant Encoding Task  $\times$  Type of Test interaction,  $F(1, 46) = 35.58, p < .001, MS_e = .040$ , indicating that the encoding task affected recognition but not priming. No other interactions approached significance.

### Discussion

The key outcome of Experiment 2 is that priming was entirely unaffected by the semantic versus nonsemantic encoding manipulation despite its large effects on recognition memory. Because we changed only the instructions for the auditory identification task between Experiments 1 and 2, we can conclude that the modest but reliable effects of the encoding task on priming in Experiment 1 were likely attributable to the use of explicit memory strategies. These data fit

Table 4  
*Proportion of Hits and False Alarms (FA) on the Auditory Recognition Test as a Function of Encoding Task (ET) and Speaker's Voice in Experiment 2*

ET	Speaker's voice		<i>M</i>	FA
	S	D		
Category	.82	.79	.81	.17
Pitch	.58	.59	.59	.29
<i>M</i>	.70	.69	.70	.23

Note. S = same; D = different.

well with previous observations that some subjects may use explicit strategies on nominally implicit tasks (cf. Bowers & Schacter, 1990; Schacter et al., 1989) and highlight the sensitivity of priming phenomena to even subtle aspects of task instructions (e.g., Graf & Mandler, 1984; but see Carr, Brown, & Charalambous, 1989, Experiment 4). More directly relevant to our central theoretical concerns, these results are consistent with the idea that priming of auditory-word identification depends on a presemantic PRS subsystem.

Despite the change in task instructions and apparent elimination of contamination from explicit memory, we again failed to observe significant effects of voice change on priming (or explicit memory). Thus, it does not look as though the absence of significant voice change effects in the priming data of Experiment 1 can be attributed to the use of explicit strategies. As in Experiment 1, there was no evidence of a larger voice change effect in the pitch condition, which required processing of voice characteristics, than in the category condition, which did not; indeed, the opposite (though non-significant) trend was observed in both experiments.

The failure to observe voice change effects on priming is consistent with Jackson and Morton's (1984) position that auditory priming effects are mediated entirely by the activation of abstract logogens that do not include or preserve information about speaker's voice. On the other hand, we did observe suggestive, albeit nonsignificant, trends for voice change effects in several conditions. Accordingly, it would be premature to concur entirely with Jackson and Morton's position, particularly as it entails acceptance of the null hypothesis.

An alternative possibility is that the absence of significant voice change effects is attributable to particular features of the auditory identification test that was used in our experiments and in Jackson and Morton's (1984) study. More specifically, the use of white noise on this task may have interfered with processing components of voice that provide access to the kind of stored information that could potentially support significantly greater priming in the same-voice condition than in the different-voice condition. Although, as discussed earlier, our evidence indicates that subjects could distinguish the pitch of male voices and female voices that were masked in noise, it is still possible that the presence of noise reduced access to more subtle voice-related components of the acoustic waveform. Of course, such an hypothesis would not account for the absence of voice change effects on the recognition test, in which noise was not used. However, there are other reasons why we might not expect voice change effects on explicit tests that we discuss later (see General Discussion); therefore for the present purposes we focus solely on priming.

Although the foregoing ideas are somewhat speculative, they do lead to a straightforward empirical prediction: If auditory priming is assessed with an implicit task that does not make use of noise, significant voice change effects should be observed. Some evidence consistent with this possibility has been reported by Gagnon and Sawusch (1990), who found voice change effects on auditory priming with naming and lexical decision tasks that did not make use of noise. However, Gagnon and Sawusch tested target items in their study im-

mediately after initial presentation, without any delay; as noted earlier, it is not clear how to relate data from an immediate testing paradigm to our experiments, in which numerous items and considerable periods of time intervened between study and test.

We attempted to address the issue in Experiment 3 under conditions that are more comparable to Experiments 1 and 2 by using an implicit task that does not involve white noise: auditory stem completion. As noted in the introduction, previous studies have demonstrated priming effects on auditory stem-completion performance and have shown that such effects are to a great extent modality specific (Bassili et al., 1989; McClelland & Pring, 1991). If, as we have speculated, white noise works against observing voice specificity effects, then auditory stem-completion priming should be higher in the same-voice condition than in the different-voice condition (note that the auditory stem-completion task differs from the auditory-identification task in ways other than the presence or absence of white noise, and we address possibly confounding influences of these differences in Experiment 5).

### Experiment 3

The basic design of Experiment 3 was similar to that of Experiments 1 and 2, with the exception of changes necessitated by the requirements of the stem-completion task. Specifically, the target words all began with single-syllable stems that allow multiple completions in order to ensure that subjects could readily provide a response when they were asked to report the first word that came to mind. Because of these constraints on the selection of target words, we were unable to use the category encoding task from Experiments 1 and 2. Accordingly, we used a semantic encoding task that requires subjects to judge the pleasantness of each word (cf. Bowers & Schacter, 1990; Graf & Mandler, 1984). Thus, as in Experiments 1 and 2, we could evaluate whether priming on the stem-completion task is influenced by the semantic versus nonsemantic study task manipulation and could also examine whether voice change effects are greater following the nonsemantic than the semantic task.

### Method

*Subjects.* Ninety-six introductory psychology students from the University of Arizona participated in Experiment 3 and received class credit for their participation.

*Materials.* Target materials consisted of 48 words that we divided into two subsets of 24 words for the encoding task. 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). We recorded target words spoken by the same six speakers (three men and three women) whom we used in Experiments 1 and 2. As in these experiments, each word was recorded in one male voice and in one female voice, so that voice changes between study and test always include a change in speaker's gender. We recorded the words on a Macintosh computer using a MacRecorder. Auditory stems were created by using the computer to edit each word so that only the first syllable was preserved.



We used six tapes to record two versions of each study list, two versions of the auditory stem-completion test, and two versions of each cued-recall test that corresponded to each study list; each item was spoken by a male voice on one version and a female voice on the other version. Each study list tape included 24 words spoken clearly. The auditory stem completion tests 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 cued-recall tests included the first syllables of the 24 words that had been presented on the study list.

We presented tapes with the same cassette deck and headphones used in previous experiments. Subjects recorded their responses in a test booklet. The first page of the test booklet contained either a 4-point scale for pitch (1 = *high*, 2 = *medium-high*, 3 = *medium-low*, and 4 = *low*) or pleasantness (1 = *unpleasant*, 2 = *moderately unpleasant*, 3 = *moderately pleasant*, and 4 = *pleasant*) and 24 numbered blanks for subjects to record their responses. The second page contained 15 letters with blank areas next to them for subjects to write in the names of cities for the distractor task; and the last page contained 48 numbered blank lines for the stem-completion task or 24 numbered blank lines for the cued-recall task.

*Design and procedure.* We used a mixed-factorial design; the between-subjects variables were encoding task (pleasantness vs. pitch) and type of test (stem completion and cued recall). The within-subjects variables were speaker's voice (same vs. different) and, for the completion task, item type (studied vs. nonstudied). 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.

We tested all subjects individually. For the encoding task, we presented 24 words auditorily and asked subjects either to rate the pitch of the speaker's voice or the pleasantness of the target word on a 4-point numeric scale. There were 5 s between words for subjects to make their ratings. The subjects then completed the distractor task, in which they generated names of U.S. cities. This task generally required 3 min to 4 min.

Immediately after the distractor task, we gave half of the subjects the stem-completion task. They were told that a series of syllables would be spoken over the headphones and that their task was to respond to each one with the first word that came to mind. Forty-eight stems—half representing studied target words, and half representing nonstudied target words—were then presented binaurally over the headphones at a normal conversational level. There were 7 s between presentation of test stems during which subjects recorded their responses in the test booklet. It is important to emphasize that there is no correct response on the completion task. Priming is assessed by comparing the proportion of target words provided as completions to stems that appeared on the study list (as initial letters of words) with the proportion of target words provided as completions to stems that did not appear on the study list (i.e., baseline completion rate). Complete counterbalancing of the experiment ensures that all words serve equally often as studied and nonstudied targets (cf. Bowers & Schacter, 1990; Graf & Mandler, 1984).

The other half of the subjects received a cued-recall task that involved the same procedure as the stem-completion task, with two changes. First, we told subjects that the test stems represented the beginnings of words that had been spoken earlier during the encoding task and that their task was to try to remember a word from the study list for each stem. Second, we used only the 24 stems that represented previously studied words.

## Results

As indicated by Table 5, there was evidence of priming on the stem-completion task in both encoding conditions, al-

Table 5

*Proportion of Target Words Reported on the Auditory Stem-Completion Test as a Function of Encoding Task (ET) and Speaker's Voice in Experiment 3*

ET	Speaker's voice			
	S	D	M	NS
Pleasantness	.45	.34	.39	.14
Pitch	.29	.24	.27	.14
<i>M</i>	.37	.29	.33	.14

*Note.* S = same; D = different; NS = nonstudied.

though the priming effect was considerably larger in the pleasantness than in the pitch condition. Most important, there was evidence of greater priming in the same voice than in the different voice conditions following both encoding tasks.

An overall *t* test that compared the proportion of studied and nonstudied stems completed with target words was highly significant,  $t(47) = 9.15$ ,  $p < .001$ , thus confirming that priming occurred. To examine the effects of the experimental manipulations on completion performance, we performed a  $2 \times 2$  ANOVA on the priming scores (i.e., proportion of studied stems completed with target words minus proportion of nonstudied stems completed with target words), with encoding task as a between-subjects variable and speaker's voice as a within-subjects variable. There was a main effect of encoding task,  $F(1, 46) = 13.96$ ,  $p < .001$ ,  $MS_e = .026$ , indicating more priming in the pleasantness than in the pitch condition. More important, there was also a significant main effect of speaker's voice,  $F(1, 46) = 9.76$ ,  $p < .01$ ,  $MS_e = .011$ , indicating that priming was lower in the different-voice condition than in the same-voice condition. However, completion rate in the different voice condition exceeded the baseline completion rate for both the pleasantness task,  $t(23) = 6.34$ ,  $p < .001$  and the pitch task,  $t(23) = 3.65$ ,  $p < .001$ . There was also a nonsignificant Speaker's Voice  $\times$  Encoding Task interaction,  $F < 1$ , which suggests that voice change effects were observed in both encoding tasks. However, because the overall magnitude of the voice change effect in the pitch condition was rather modest, we performed planned comparisons of completion rates in the same- and different-voice conditions for each encoding task. For the pleasantness condition, completion performance was significantly higher in the same-voice condition than in the different-voice condition,  $t(23) = 2.35$ ,  $p < .05$ , whereas for the pitch condition, the effect failed to achieve statistical significance,  $t(23) = 1.48$ .

The data from the cued-recall test are presented in Table 6. Two outcomes are apparent: Recall performance was much higher following the pleasantness task than following the pitch task, and there was little effect of voice change on the level of recall in either encoding task. Analysis of variance revealed a highly significant main effect of encoding task,  $F(1, 95) = 57.12$ ,  $p < .001$ ,  $MS_e = .026$ , together with a nonsignificant main effect of speaker's voice and a nonsignificant Encoding Task  $\times$  Speaker's Voice interaction (both  $F_s < 1$ ).

To examine the relation between completion and cued-recall performance more directly, we performed a combined ANOVA on the proportion of correct responses for studied



Table 6  
*Proportion of Target Words Reported on the Auditory Cued-Recall Test as a Function of Encoding Task (ET) and Speaker's Voice in Experiment 3*

ET	Speaker's voice		M
	S	D	
Pleasantness	.66	.62	.64
Pitch	.39	.39	.39
M	.53	.51	.52

Note. S = same; D = different.

items in which type of test and encoding task were between-subjects variables and speaker's voice was a within-subjects variable. The critical outcome was a significant Encoding Task  $\times$  Type of Test interaction,  $F(1, 92) = 6.66, p < .02, MS_e = .011$ , thus indicating that the encoding manipulation influenced explicit recall more than priming. There was also a marginally significant Speaker's Voice  $\times$  Type of Test interaction,  $F(1, 92) = 2.83, p < .10, MS_e = .011$ , suggesting that voice change affected priming more than explicit recall. No other interactions approached significance.

### Discussion

The critical outcome of Experiment 3 was that priming effects on an auditory stem completion task were reduced significantly by a study-to-test change in speaker's voice. This result contrasts with the data from Experiments 1 and 2, in which no significant effects of voice change were observed on priming of auditory identification performance. However, significant priming was still observed in the different-voice condition, thereby indicating the presence of voice-specific and voice-nonspecific components of priming on the auditory stem-completion task. The data are thus broadly consistent with our suggestion that the absence of voice effects on the auditory identification test is attributable to the presence of white noise.

Although priming was generally lower in the different-voice condition than in the same-voice condition, the voice change effect achieved significance only for the pleasantness rating task; there was a small, nonsignificant effect for the pitch rating task. Accordingly, the completion data provide only limited support for our hypotheses about the basis of voice change effects in priming. In addition, these data are rather puzzling in relation to Graf and Ryan's (1990) finding that specificity effects in visual priming were observed only following encoding tasks that focused subjects' attention on perceptual characteristics of words. To the extent that the pitch task, but not the pleasantness task, focused subjects' attention on characteristics of speakers' voices, we would have expected to observe larger voice change effects in the pitch condition than in the pleasantness condition.

There are, however, reasons to suspect that our choice of encoding tasks may not have been entirely appropriate. With respect to the pleasantness task, although we instructed subjects to rate the pleasantness of the words themselves, it is quite possible that they often included an assessment of the pleasantness of the speaker's voice as part of their rating; indeed, some subjects commented that it was difficult to

separate rating the pleasantness of a word from the pleasantness of the voice by which it was spoken (cf. Mullennix & Pisoni, 1990). Thus, this nominally semantic encoding task, when performed in the context of our experimental paradigm, may also have included an auditory or perceptual component, and it is the latter component that might have produced robust voice change effects. By contrast, although the pitch task clearly required subjects to attend to the speaker's voice, subjects may have focused solely on voice characteristics and not on the relation between the voice and the word. It is conceivable that a nonsemantic encoding task will produce robust voice effects on priming—perhaps larger effects than a semantic task—when it induces subjects to focus on voice characteristics in relation to a particular word that is spoken.

The nature of the encoding tasks may also be related to an additional outcome of Experiment 3: There was significantly more priming in the pleasantness condition than in the pitch condition. This result is not consistent with the hypothesis that auditory priming on the stem-completion task is driven by a presemantic subsystem. Although the hypothesis receives partial support from the Encoding Task  $\times$  Type of Test interaction—type of encoding had a smaller effect on priming than on explicit memory—the significant effect of encoding task on the magnitude of priming requires explanation. If, as suggested previously, the pleasantness rating task also includes an auditory or perceptual component, then it is possible that this perceptual component—and not semantic processing—accounts for the larger priming effects observed in the pleasantness condition than in the pitch condition. To address both of the foregoing concerns, we performed an additional stem-completion experiment using different encoding tasks.

### Experiment 4

Our main goal in Experiment 4 was to select a semantic encoding task that does not focus attention on voice characteristics and a nonsemantic encoding task that requires subjects to attend to voice characteristics in relation to the word that is spoken. Consistent with these objectives, in the semantic encoding condition we used a meaning-rating task in which subjects rated each word on a 4-point scale according to the number of meanings associated with it. Some of the target words had a number of alternative meanings (e.g., *marble*), whereas others had only a single meaning (e.g., *perfume*). Rating the number of meanings for each word presumably focuses attention onto semantic memory and away from the speaker's voice. By contrast, in the nonsemantic encoding condition we used a clarity-rating task in which subjects rated, also on a 4-point scale, how clearly each speaker enunciated each word. This task required subjects to process voice information with reference to the target words.

### Method

*Subjects.* Forty-eight Harvard University undergraduates took part in Experiment 4 and were paid \$5 for their participation.

*Materials, procedures, and design.* The target materials and voices used in Experiment 4 were identical to those used in Experiment 3, and we used the same basic procedures and design, with three exceptions. First, the meaning-rating and clarity-rating encoding

tasks were used instead of the pleasantness and pitch tasks. For the meaning-rating task, we told subjects that they would hear a series of words, some of which had a number of meanings and some of which had only a single meaning. We told them to rate the number of meanings for each word on a 4-point scale (1 = *one*, 2 = *two*, 3 = *three*, or 4 = *four or more meanings*). For the clarity-rating task, we told subjects that they would hear series of words read by different speakers who varied in how clearly they pronounced each word. We instructed subjects to rate clarity of enunciation for each word on a 4-point scale (1 = *poor*, 2 = *moderately poor*, 3 = *moderately well*, or 4 = *well*).

Second, in Experiment 4 we gave the cued-recall task after the completion test, whereas in Experiment 3 we gave the two tests to separate groups. Because levels of processing effects on explicit recall tasks are well established, and we observed such an effect in Experiment 3, a separate group for the cued-recall test was deemed unnecessary. Third, the cued-recall task included all 48 stems of studied and nonstudied words that appeared on the completion test, instead of only the 24 stems of studied items. The main reason for this change was to make the completion and recall tests more closely comparable. As on the completion test, initial syllables of studied and nonstudied words were randomly intermixed on the recall test. We told subjects to try to remember a word from the study list in response to each syllable, but we also informed subjects that some of the stems did not represent study list words. We further instructed subjects to write a word only when they remembered it from the study list because the syllables had also just been presented in the previous stem-completion task.

## Results

The data from the completion task, presented in Table 7, are relatively clear-cut: Priming scores (i.e., studied minus nonstudied) were identical following the meaning (.24) and clarity (.24) encoding tasks, whereas they were considerably lower in the different-voice condition (.19) than in the same-voice condition (.30).

An overall *t* test comparing the proportion of studied and nonstudied stems completed with target words confirmed that significant priming occurred,  $t(47) = 15.75, p < .001$ . A  $2 \times 2$  ANOVA that included encoding task as the between-subjects variable and speaker's voice as the within-subjects variable was performed on the priming scores. The analysis revealed a negligible main effect of encoding task,  $F < 1$ , a significant effect of speaker's voice,  $F(1, 46) = 28.32, p < .001, MS_e = .009$ , and a nonsignificant interaction between these two variables,  $F(1, 46) = 1.83, MS_e = .009$ . Although priming was lower in the different-voice than in the same-

voice condition, completion rate in the different-voice condition exceeded baseline completion levels for both the meaning task,  $t(23) = 8.57, p < .001$ , and the clarity task,  $t(23) = 5.33, p < .001$ . In addition, the voice change effect was significant for each encoding task: Priming scores in the same-voice condition were significantly higher than in the different-voice condition for both the meaning task,  $t(23) = 3.29, p < .01$ , and the clarity task,  $t(23) = 2.27, p < .05$ .

The pattern of results from the cued-recall test was the opposite of that observed on the completion task: Explicit memory was much higher following the meaning task than the clarity task—corrected recall scores (i.e., proportion of target words produced to stems that represent studied items minus proportion of target words produced to stems that represent nonstudied items) were .53 in the former condition and .22 in the latter—and there was little effect of voice change in either condition (see Table 8). A  $2 \times 2$  ANOVA was performed on the corrected recall scores. The analysis revealed a highly significant effect of encoding task,  $F(1, 46) = 13.28, p < .001, MS_e = .64$ , a nonsignificant effect of speaker's voice,  $F < 1$ , and a nonsignificant Encoding Task  $\times$  Speaker's Voice interaction,  $F < 1$ .

To compare completion and recall performance more directly, we performed an additional ANOVA that included type of test as a within-subjects factor. This analysis revealed two significant interactions: Encoding Task  $\times$  Type of Test,  $F(1, 46) = 26.26, p < .001, MS_e = .043$ , and Speaker's Voice  $\times$  Type of Test,  $F(1, 46) = 7.94, p < .01, MS_e = .012$ . The former analysis indicates that recall but not completion performance was higher following the meaning task than the clarity task, whereas the latter indicates that completion but not recall performance was higher in the same-voice than the different-voice condition. The three-way interaction of Encoding Task  $\times$  Speaker's Voice  $\times$  Type of Test did not approach significance,  $F < 1$ .

## Discussion

The results of Experiment 4 provide strong evidence that priming of auditory stem-completion performance is sensitive to study-to-test changes in speaker's voice, and the results also demonstrate clearly that such priming need not involve semantic study processing. A number of previous experiments using various implicit memory tasks have shown that semantic study processing differentially improves explicit memory in relation to priming (e.g., Bowers & Schacter, 1990; Graf &

Table 7  
Proportion of Target Words Reported on the Auditory Stem-Completion Test as a Function of Encoding Task (ET) and Speaker's Voice in Experiment 4

ET	Speaker's voice		M	NS
	S	D		
Meaning	.49	.36	.42	.18
Clarity	.42	.34	.38	.14
M	.46	.35	.40	.16

Note. S = same; D = different; NS = nonstudied.

Table 8  
Proportion of Target Words Reported on the Auditory Cued-Recall Test as a Function of Encoding Task (ET) and Speaker's Voice in Experiment 4

ET	Speaker's voice		M	NS
	S	D		
Meaning	.62	.59	.61	.08
Clarity	.42	.42	.42	.20
M	.52	.51	.52	.14

Note. S = same; D = different; NS = nonstudied.

Mandler, 1984; Jacoby, 1983; Jacoby & Dallas, 1981; Schacter & Graf, 1986); other experiments have shown that study and test changes in surface feature information differentially impair priming in relation to explicit memory (e.g., Marsolek, Kosslyn, & Squire, 1992; Weldon & Roediger, 1987); and Graf and Ryan's (1990) experiments revealed differential effects of semantic versus nonsemantic study tasks on priming and explicit memory under conditions in which study-to-test changes in surface features had similar effects on the two forms of memory. To our knowledge, however, our study is the first to demonstrate, within a single experiment, opposite effects of semantic versus nonsemantic study processing and study-to-test changes in surface feature information on priming and explicit memory.

The data are consistent with our hypotheses regarding the inadequacies of the encoding tasks used in Experiment 3, suggesting that the equivocal evidence for voice effects that was observed in the pitch-encoding condition and the enhanced overall priming that was observed in the pleasantness condition are likely attributable, at least in part, to the factors discussed earlier. Note, however, that despite using a nonsemantic encoding task that required subjects to focus on voice characteristics in relation to the particular word that was spoken, we failed to uncover evidence for stronger voice change effects in the clarity-rating condition than in the meaning-rating condition. Thus, in contrast to Graf and Ryan's (1990) observations on visual priming, our data do not indicate that perceptual specificity effects in auditory priming are observed only with encoding tasks that focus attention on perceptual features of target items. We return to this issue in the General Discussion.

Viewed in relation to the results of Experiments 1 and 2, the data from Experiment 4 are consistent with our hypothesis that significant voice change effects were not observed on the auditory identification task because of effects attributable to the presence of white noise. However, comparison of Experiments 1 and 2 on the one hand and Experiments 3 and 4 on the other suggest two reasons to be cautious about accepting this hypothesis. First, as noted earlier, the identification and completion tasks differed from each other in a way other than the presence or absence of white noise: The entire word was spoken in the identification task, whereas only the first syllable was presented in the completion task. Second, the encoding tasks that yielded evidence of significant voice change effects on completion performance (pleasantness, meaning, and clarity ratings) were not the same as the encoding tasks that failed to produce evidence of significant voice change effects on identification performance (category and pitch ratings).

To provide a firmer empirical basis for assessing our hypotheses, it is necessary to determine whether the presence or absence of voice change effects is attributable to differences in test requirements and encoding tasks. We attempted to achieve this objective by performing an additional experiment using the same encoding tasks and completion test as in Experiment 4, making only a single change: We presented the stems on the completion test in white noise. According to our hypotheses, significant voice change effects on priming should not be observed under these conditions.

## Experiment 5

In attempting to develop a viable completion task that made use of white noise, we conducted a pilot study in which we masked test syllables with the same levels of noise that were used in Experiments 1 and 2. However, the resulting stimuli were so degraded that subjects were unable to respond appropriately to them. Accordingly, it was necessary to use lower levels of white noise than were used in Experiments 1 and 2 in order to create conditions under which a basic priming effect could be observed. However, this difference from Experiments 1 and 2 works against our hypothesis, because using lower levels of noise would create conditions more favorable for observing voice specificity effects than would the conditions that obtained in Experiments 1 and 2.

### Method

*Subjects.* Forty-eight Harvard University undergraduates participated in Experiment 5 in exchange for a \$5 payment.

*Materials, design, and procedure.* All aspects of materials, design, and procedure described with respect to the completion test were identical to those of Experiment 4, except that the syllables that constituted the test stems were masked by white noise. In addition, we dropped the cued-recall test. As in Experiments 1 and 2, white noise was generated and mixed with target items using a Macintosh computer. In Experiments 1 and 2 we presented most of the words with the maximum noise level that the program produced. In the present experiment, it was necessary to reduce the amount of noise in order to obtain acceptable levels of performance. The noise was reduced until pilot subjects began to show some evidence of above-zero completion rates in response to the target stems. Overall, we reduced noise levels by approximately 50% in relation to maximum levels.

### Results and Discussion

We performed a preliminary ANOVA with speaker's gender as a within-subjects factor that revealed, in contrast to Experiments 1–4, a significant main effect of speaker's gender,  $F(1, 47) = 12.59, p < .01, MS_e = .016$ , indicating more target-word completions to female than to male voices. However, there were no significant interactions with other independent variables ( $F_s < 2.68$ ). It is not clear why a main effect of speaker's gender was observed in Experiment 5 but not in any other experiment, and we do not consider the finding further.

As indicated by the data in Table 9, baseline levels of completion performance were lower than those observed in Experiments 3 and 4, and the overall magnitude of the priming effect was not as large. Nevertheless, a substantial priming effect was observed for both encoding tasks: Overall completion rate for studied items was significantly higher than for nonstudied items,  $t(23) = 7.82, p < .001$ . Priming scores were identical in the meaning (.09) and clarity (.09) encoding conditions, and most important, priming scores were quite similar in the same-voice (.10) and different-voice (.08) conditions. An ANOVA that was performed on the priming scores revealed nonsignificant main effects of speaker's voice,  $F(1, 46) = 1.64, MS_e = .007$ , and encoding task,

Table 9  
*Proportion of Target Words Reported on the Auditory Stem-Completion Test with White Noise as a Function of Encoding Task (ET) and Speaker's Voice in Experiment 5*

ET	Speaker's voice		M	NS
	S	D		
Meaning	.14	.12	.13	.04
Clarity	.14	.11	.13	.04
M	.14	.12	.13	.04

Note. S = same; D = different; NS = nonstudied.

$F(1, 46) < 1$ , as well as a nonsignificant Encoding Task  $\times$  Speaker's Voice interaction,  $F(1, 46) < 1$ .

When considered in relation to the robust voice change effects observed in Experiment 4, these data support the hypothesis that presence or absence of voice change effects on the auditory completion task depend on the presence or absence of white noise, because we held all aspects of Experiments 4 and 5 constant except for this variable. These results are also consistent with our hypothesis that the failure to observe effects of changing voice on priming in Experiments 1 and 2 was indeed attributable to the use of white noise on the auditory identification task. However, one possible problem with Experiment 5 is that subjects could give nontarget completions for either of two reasons: (a) they might perceive the stem correctly yet fail to provide the target word, or (b) they might fail to perceive the stem correctly (because of the white noise) and hence necessarily provide a response other than the target word. By contrast, in Experiment 4, in which there was no white noise and subjects had no difficulty perceiving the correct stems, only the first of the two reasons for nontarget responses would obtain.

To address the issue, we conducted two additional analyses. First, we examined whether more stems of previously studied words were perceived correctly as a function of speaker's voice or encoding task (a stem was scored as *perceived correctly* when either the list target was provided or when a word was provided whose pronunciation was consistent with that of the stem; a stem was scored as *perceived incorrectly* when a subject provided a word whose pronunciation was inconsistent with that of the stem). The ANOVA revealed no significant main effects or interactions ( $F_s < 1.25$ ). However, the analysis did reveal that subjects perceived the stem correctly for only .40 of studied items. Accordingly, we performed a second analysis in which the proportion of target responses was conditionalized on correct perception of the stem. The analysis revealed a numerical trend for higher levels of completion performance in the same-voice condition (.34) than in the different-voice condition (.30), but an ANOVA indicated that the main effect of speaker's voice did not approach significance,  $F(1, 46) = 1.15$ ,  $MS_e = .045$ . The ANOVA also revealed a nonsignificant effect of encoding task and a nonsignificant Encoding Task  $\times$  Speaker's Voice interaction (both  $F_s < 1$ ). There was, however, a robust overall priming effect in these data, as indicated by the fact that completion rate for studied items was significantly greater than for nonstudied items,  $t(47) = 6.51$ ,  $p < .001$ . Thus, this analysis indicates

that the lack of significant voice change effects in Experiment 5 is not attributable to some sort of artifact produced by failures to perceive the stem correctly.

## General Discussion

These experiments have yielded a number of new experimental facts about implicit and explicit memory in the auditory domain. Experiments 1 and 2 showed that priming on an auditory identification test was less affected than was explicit recognition by manipulations of semantic versus nonsemantic study processing, and they also revealed that both implicit and explicit memory were unaffected by study-to-test changes in speaker's voice. Experiments 3 and 4 showed differential effects of semantic and nonsemantic study tasks on auditory stem completion and cued recall, and in addition they revealed significant voice change effects on priming but not on explicit memory. Experiment 5 indicated that significant voice change effects on completion performance are no longer observed when test stems are embedded in white noise. These results bear on a number of empirical and theoretical issues, and we consider each of them in turn.

One general point to highlight is that the present data provide, to our knowledge, the first evidence that priming on auditory identification and completion tasks can be dissociated experimentally from explicit memory. Previous studies of priming with auditory identification and completion tasks have not included explicit memory tests and, hence, have not been designed to provide evidence for implicit and explicit dissociation (cf. Bassili et al., 1989; Ellis, 1982; Franks, et al., 1982; Jackson & Morton, 1984; Jacoby et al., 1988; McClelland & Pring, 1991). Because performance on nominally implicit tasks can often be contaminated by explicit retrieval, it is critical to provide evidence for implicit and explicit dissociation to make theoretical inferences about the nature of priming (e.g., Schacter et al., 1989). By doing so, our experiments help to establish an empirical foundation for understanding the relation between implicit and explicit memory for auditory information.

We began by noting that certain brain-damaged patients exhibit dissociations between relatively intact access to knowledge of auditory word forms and severely impaired access to knowledge of semantic information from auditory input, thereby suggesting the existence of a presemantic auditory PRS subsystem; we hypothesized that this subsystem might subservise various kinds of auditory priming effects. Our data are largely consistent with this view: In each of Experiments 1-4, the semantic versus nonsemantic study task manipulation had larger effects on explicit memory than on priming. Although priming was influenced significantly by the study task manipulation in Experiments 1 and 3, we had reason to suppose that this effect was attributable to the influence of explicit memory in Experiment 1 and to the use of an inappropriate encoding task in Experiment 3. Experiments 2 and 4 (which were modified to take account of the hypothesized problems) revealed no effects of semantic versus nonsemantic encoding manipulations on priming despite large effects of the same manipulations on explicit memory, which is consistent with our notions.

We acknowledge that the foregoing results are compatible with a number of theoretical approaches to implicit memory (cf. Graf & Mandler, 1984; Jacoby, 1983; Roediger, 1990), and do not support the PRS view uniquely. Nevertheless, we want to emphasize that our proposal of an auditory PRS subsystem was not put forward in response to the priming data; rather, it was formulated on the basis of independent neuropsychological evidence (see Schacter, 1992, for a general discussion of this point). Taken together, our results and the neuropsychological data provide converging evidence for the existence of such a subsystem. In a recent neuropsychological study, we have examined a further prediction of the PRS view—namely, that patients who exhibit auditory comprehension deficits (e.g., word meaning deafness) should show intact priming. We assessed the performance of one such patient on the auditory identification task described in Experiment 2, and we found that the patient showed normal priming in relation to matched controls despite a substantial auditory comprehension deficit (Schacter, McGlynn, Milberg, & Church, 1992). Though only a single case, this study provides additional converging support for the PRS account.

Turning to the effects of the voice manipulation, the overall pattern of results is consistent with the hypothesis that voice change effects in priming depend critically on the presence or absence of white noise on an implicit test. Thus, it seems reasonable to suggest that noise interferes with processing aspects of the acoustic waveform that code voice information. We cannot yet say very much about the exact basis of these effects. Nevertheless, we would like to suggest a speculative possibility that emerges from considering the auditory processing capacities of the left and right hemispheres. Zaidel (1978) reported that the right hemisphere of split-brain patients has greater difficulty than the left hemisphere when processing spoken words that are presented in background noise. There are both empirical and theoretical reasons to postulate that the right hemisphere plays a special role in the processing and representation of voice information. Several investigators (cf. Liberman, 1982; Mann & Liberman, 1983; Zaidel, 1985) have argued that the left hemisphere operates on categorical or abstract auditory information (e.g., phonemes) and discards or ignores noncategorical information in the speech signal, such as voice characteristics of a particular speaker; the right hemisphere, by contrast, is argued to operate on noncategorical “acoustic gestalts” and to preserve information about prosodic features of speech, including characteristics of a particular speaker’s voice.

Various kinds of evidence link the right hemisphere with access to voice information. On the one hand, neuropsychological studies indicate that patients with right-hemisphere lesions show deficits in voice recognition (e.g., Van Lancker & Kreiman, 1987) and in processing prosodic aspects of speech (e.g., Coslett et al., 1987; Ross, 1981). On the other hand, dichotic listening studies with normal subjects have revealed a left-ear advantage for processing aspects of voice information (i.e., intonational contours; Blumstein & Cooper, 1974; Shipley-Brown, Dingwall, Berlin, Yeni-Komshian, & Gordon-Salant, 1988).

To the extent that the auditory processing abilities of the right hemisphere are especially impaired by noise (Zaidel,

1978), our finding that voice specificity effects in priming depend on the presence or absence of white noise raises the possibility that voice-specific priming is based on a right-hemisphere subsystem, whereas abstract priming that occurs across different voices is based on a left-hemisphere subsystem. That is, when we used white noise on identification and completion tasks, we may have also minimized the possible contribution of the right hemisphere to priming and correspondingly reduced the likelihood of observing voice change effects. Although highly speculative, it is worth pointing out that a recent study of visual stem-completion priming by Marsolek et al. (1992) revealed that study-to-test changes of visual surface feature information (i.e., case of words) were observed only when test stems were presented to the right hemisphere; no specificity effects were found when stems were presented to the left hemisphere. It is thus possible that the right hemisphere mediates perceptual specificity effects in both the visual and auditory domains.

Because our experiments have not provided evidence that directly links voice change effects in priming with the right hemisphere, the foregoing ideas must be treated cautiously. Nevertheless, they may prove useful heuristically by suggesting experiments that do provide more direct tests of possible right hemisphere involvement in voice-specific priming, either by using procedures such as dichotic listening or by examining neurological patients with relevant disorders. In fact, we have initiated experiments on auditory stem completion using a dichotic listening procedure, and we have observed preliminary evidence that the right hemisphere is more impaired by study-to-test voice changes than is the left hemisphere (Schacter, Aminoff, & Church, 1992).

Whatever the ultimate explanation of the observed patterns of voice-related effects, the fact that we did find clear evidence that priming on the completion task is reduced by voice change (Experiments 3 and 4), and that this effect cannot be attributed to the influence of explicit memory (Experiment 4), provides evidence against Jackson and Morton’s (1984) hypothesis that auditory priming is mediated entirely by activation of an abstract auditory logogen that is indifferent to speaker’s voice. Of course, our data do indicate that there is a substantial abstract component to auditory priming: The magnitude of the voice change effect that we did observe was relatively modest, and we consistently found evidence for priming in the different-voice condition. If, as we speculated earlier, there are indeed two presemantic subsystems that contribute to priming—one operating on abstract phonological information, the other on voice-specific acoustic information—then the evidence to date suggests that the former subsystem plays a more prominent role than the latter in auditory priming paradigms of the kind that we have described in this article. Our data, however, do show that something more than abstract phonological information is involved in priming. In this respect, our results are similar to findings from experiments on perceptual specificity in the visual domain, in which changing surface features of target items reduces priming effects in certain experimental conditions yet has little or no influence on priming in other conditions (cf. Carr et al., 1989; Graf & Ryan, 1990; Jacoby, Levy, & Steinbach, 1992; Kirsner et al., 1989; Marsolek et al., 1992).

At the same time, however, we failed to observe any evidence that voice change effects are enhanced by study tasks that require subjects to focus on voice characteristics; if anything, we observed nonsignificant trends in the opposite direction. In Experiments 1, 2, and 5, significant voice change effects failed to emerge following semantic encoding tasks that did not focus on voice characteristics and nonsemantic encoding tasks that did; in Experiments 3 and 4, we observed voice change effects of comparable magnitude following both types of tasks, except for the nonsemantic (i.e., pitch) encoding condition of Experiment 3, which produced equivocal evidence for voice change effects. Thus, our findings differ from Graf and Ryan's (1990) data on visual priming, that indicate that effects of study-to-test changes in typefont require specific encoding of visual features of target items during a study task. To the extent that the Graf and Ryan results support a transfer-appropriate processing approach, in which priming depends on the match between processing operations performed at study and test (e.g., Roediger, 1990; Roediger et al., 1989), our data do not provide support for such an orientation.

We can only speculate as to why we failed to observe the sort of transfer-appropriate processing effects that Graf and Ryan (1990) did. One point worth noting is that Graf and Ryan observed similar patterns of specificity effects on implicit and explicit memory, whereas we did not observe significant voice change effects in explicit memory. It is thus conceivable that the specificity effects in priming observed by Graf and Ryan are related to explicit memory in a way that our effects are not, although aspects of Graf and Ryan's results make it unlikely that their specificity effects are directly attributable to explicit memory (see Graf & Ryan's Experiment 3). Another possibility emerges from considering the PRS framework: Assuming that the priming effects in Graf and Ryan's experiments were mediated largely by a visual PRS subsystem, whereas our priming effects were mediated by a separate auditory subsystem, it is conceivable that the nature of transfer-appropriate processing differs in the two subsystems. For example, as pointed out by Goldinger, Pisoni, and Logan (1991), there is evidence that some sort of encoding of voice information may be an obligatory component of speech perception. If so, then varying the requirements of encoding tasks would not have a large impact on the magnitude of voice change effects. By contrast, encoding the particular fonts of written words may not be an obligatory component of reading (e.g., Carr et al., 1989; Jacoby et al., 1992) and hence may require special types of study tasks. It seems clear that these and other possibilities ought to receive serious attention in future research.

Some comments are also in order regarding the absence of significant voice change effects on explicit recognition and recall tests in any of the experiments, because these results cannot be attributed to the presence of white noise. Let us first point out that we do not interpret this outcome as indicating that voice information is unavailable for explicit recall or recognition. A number of experiments have shown that subjects can explicitly remember voice information when asked to do so (e.g., Geiselman & Bellezza, 1976, 1977; Geiselman & Crawley, 1983) and that circumstances exist under which variations in voice information can influence

explicit recall and recognition (e.g., Craik & Kirsner, 1974; Goldinger et al., 1991; Martin, Mullennix, Pisoni, & Summers, 1989). It is worth noting, however, that the conditions under which access to voice information on explicit tests has been demonstrated are rather circumscribed. For example, the work of Geiselman and colleagues has lent support to the idea that explicit memory for speaker's voice requires relating voice information to speaker characteristics (e.g., personality type and biographical information). Indeed, Geiselman and Bellezza (1977) reported chance levels of voice recognition following an incidental encoding task. Similarly, the talker variability effects reported by Goldinger et al. (1989) and Martin et al. (1989)—enhanced recall of words spoken by a single voice in comparison with multiple voices—are observed only for the primacy items from the study list. Craik and Kirsner found that changing speaker's voice reduced yes or no recognition accuracy in a continuous recognition paradigm, but the magnitude of the voice change effects were generally small, and they were observed with brief delays (less than 2 min) between the first and second appearance of an item. Moreover, Craik and Kirsner noted that some of the observed effects may have been attributable to strategic coding of semantic links between words and voices. Thus, the evidence for explicit recollection of voice information in episodic memory paradigms is not exactly overwhelming.

Nevertheless, we think that it is reasonable to assume that some voice information is encoded and retained by the episodic system that supports explicit recall and recognition. We also assume that changing speaker's voice between study and test has little effect on cued recall and recognition performance because subjects tend to rely on conceptually driven processes and strategies when performing such tasks, thereby overriding the potential importance of voice as a useful cue for explicit retrieval. On an implicit test such as stem completion, however, performance is driven more directly by physical properties of test cues (cf. Jacoby, 1983; Roediger & Blaxton, 1987) and, according to our view, relies more heavily on the output of PRS subsystems. Further examination of the relation between implicit and explicit memory for voice information is just one of several critical tasks for future research in the generally underexplored territory of implicit memory for auditory information.

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