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# Auditory Priming for Nonverbal Information: Implicit and Explicit Memory for Environmental Sounds

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Three experiments examined repetition priming for meaningful environmental sounds (e.g., clock ticking, tooth brushing, toilet flushing, etc.) in a sound stem identification paradigm using brief sound cues. Prior encoding of target sounds together with their associated names facilitated subsequent identification of sound stems relative to nonstudied controls. In contrast, prior exposure to the names alone in the absence of the environmental sounds did not prime subsequent sound stem identification performance at all (Experiments 1 and 3). Explicit and implicit memory were dissociated such that sound stem cued recall was higher following semantic than nonsemantic encoding, whereas sound priming was insensitive to manipulations of depth of encoding (Experiments 2 and 3). These results extend the findings of long-term repetition priming into the auditory nonverbal domain and suggest that priming for environmental sounds is mediated primarily by perceptual processes.

## INTRODUCTION

The distinction between implicit and explicit memory has been a subject of intense theoretical and empirical scrutiny in recent years. In explicit memory tests (e.g., free and cued recall, recognition, etc.) subjects are asked to consciously remember a prior episode, whereas in implicit memory tests (e.g., stem or fragment completion, perceptual identification, naming, etc.) performance is influenced by the prior learning episode without necessarily involving such conscious recollection. The most commonly studied class of implicit memory tests involves identification or completion of perceptually degraded versions of the targets that have been previously studied. When prior experience with the targets produces subsequent specific transfer relative to nonstudied items, perceptual priming is said to be demonstrated.

Numerous studies have shown that explicit memory and perceptual priming can be dissociated (for review see Ochsner, Chiu, & Schacter, 1994; Richardson-Klavehn & Bjork, 1988; Roediger & McDermott, 1993; Roediger, Weldon, & Challis, 1989; Schacter, Chiu, & Ochsner, 1993; Squire, 1992). For instance, early studies showed that amnesic patients, who are often severely impaired in explicit memory, can nevertheless exhibit normal levels of perceptual priming. In addition, perceptual priming can be dissociated from explicit memory as a function of two general classes of independent variables. Explicit memory tends to benefit from semantic encoding of the targets during study relative to nonsemantic encoding, whereas perceptual prim-

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ing tends to be less affected or unaffected by semantic or elaborative encoding. On the other hand, perceptual priming is often more sensitive than explicit memory to the compatibility in surface features of targets between study and test. On the basis of such evidence, the set of relevant processes that mediates perceptual priming have been characterized as stimulus- or data-driven (e.g., Jacoby, 1983; Roediger et al., 1989), perceptual/higher-order (e.g., McDermott & Roediger, 1994), automatic and episodic (e.g., Jacoby, Toth, & Yonelinas, 1993), tapping the perceptual record of experience (e.g., Kirsner, Dunn, & Standen, 1989) or supported by a perceptual representation system (PRS) that primarily process and represent domain-specific information about the form and structure of perceptual objects (e.g., Schacter, 1994; Tulving & Schacter, 1990).

One finding that seems to contradict this parsimonious account of perceptual priming is that even extreme changes in perceptual form of the stimuli between study and test often fail to eliminate priming completely (see Roediger & McDermott, 1993; Schacter et al., 1993, for a review). For instance, study-to-test changes in sensory modality (i.e., either from visual study to auditory test or from auditory study to visual test) almost invariably yield significant cross-modal priming on perceptual implicit tests (e.g., Bassili, Smith, & MacLeod, 1989; Craik, Moscovitch, & McDowd, 1994; Donnelly, 1988; Jackson & Morton, 1984; Kelley, Jacoby, & Hollingshead, 1989; McClelland & Pring, 1991; Rajaram & Roediger, 1993; Srinivas & Roediger, 1990; Weldon, 1991; Weldon & Roediger, 1987; but see Gipson, 1986, and Jacoby & Dallas, 1981, for exceptions). The finding of significant priming across surface form variations directly challenges the idea that priming on identification and completion tests is mediated purely by perceptual processes, because the stimuli at study share no common perceptual attributes with the stimuli at test. Indeed, it has been suggested that priming across surface form variations in general, and priming across presentation modality in particular, reflects either contamination of the implicit test by explicit recollection (e.g., Jacoby et al., 1993) or substantial involvement of semantic processes (e.g., Masson & MacLeod, 1992; Toth & Hunt, 1990).

However, more convincing evidence for the perceptual nature of priming is provided by studies that have examined transfer between perceptual forms such as words and pictures. Although a handful of studies have found small cross-form priming between picture and words (e.g., Brown, Neblett, Jones, & Mitchell, 1991; Hirshman, Snodgrass, Mindes, & Feenan, 1990; Weldon & Jackson-Barrett, 1993, Experiment 1; Weldon & Roediger, 1987), many others have reported complete absence of cross-form priming (e.g., Roediger, Weldon, Stadler, & Riegler, 1992; Rajaram & Roediger, 1993; Srinivas, 1993; Srinivas & Roediger, 1990; Weldon, 1991, 1993; Weldon & Jackson-Barrett, 1993, Experiment 2 and 3; Weldon & Roediger, 1987; Weldon, Roediger, Beitel, & Johnston, 1995). McDermott and Roediger (1994) recently showed that exposure to printed words led to priming on a picture fragment naming test if and only if subjects had formed mental images of the corresponding pictures during study. All in all, the data suggest that when people are given words to study in the absence of any imagery instructions and later tested with pictures, priming is completely eliminated.

Because of its key implications for perceptually oriented accounts of priming, the elimination of cross-form priming effects is a theoretically important result. Yet all of the available evidence derives from studies in the visual modality using pictures and words. In the present experiments, we seek to test the generality of these findings in the auditory nonverbal domain. To do so, we examined priming of environmental sounds. Subjects studied target materials under a variety of conditions, defined by the orthogonal combinations of (a) type of encoding task (either semantic or nonsemantic) and (b) stimulus form (either names of environmental sounds only or the same names together with the corresponding sounds). After a filled delay, subjects were given an auditory nonverbal test with either implicit or explicit retrieval instructions.

In addition to allowing us to assess the generality of previous results concerning cross-form priming, a second purpose of our experiments is to extend work on repetition priming into the auditory nonverbal domain. Given that available data on auditory perceptual priming come from studies using verbal materials (e.g., Church & Schacter, 1994; Schacter & Church, 1992), it remains to be determined whether auditory perceptual priming for nonverbal information exhibit the same characteristics as its verbal counterpart. Although a handful of recent studies (Ballas, 1993; Van Petten & Rheinfelder, 1994) have used short-term priming paradigms to explore issues related to the mental representation of environmental sounds, no studies to date have systematically examined long-term perceptual priming in this domain. The present experiments seek to fill this gap.

## EXPERIMENT 1

To assess priming of environmental sounds, we have developed an auditory sound stem identification task that is similar in some respects to stem completion tasks previously used to assess visual and auditory priming of familiar words. In this paradigm, subjects initially study environmental sounds that last for 5 s. In the subsequent test phase, subjects hear brief 1-s segments of studied and nonstudied sounds. Their task is to identify each test sound by giving the first sound name that comes to mind. A sound stem cued recall task served as a comparable task for assessing explicit memory: the same sound cues are presented to subjects but with instructions that subjects are to use the sound stems to help them recall a stimulus experienced earlier during encoding.

We compared sound stem identification and sound stem cued recall in Experiment 1 following different forms of stimulus presentation under different encoding conditions. All subjects were presented with a mixed list in which half of the stimuli appeared in name-and-sound form and half of the stimuli in name-only form. Each name provided a short description of the corresponding sound in the form of an event depicting an action and an object (e.g., toilet flushing, tooth brushing, dialing rotary phone, etc.). One group of subjects performed a semantic encoding task and a separate group of subjects performed a nonsemantic encoding task designed to focus subjects' attention on the perceptual characteristics of the environmental sounds.

We had a number of expectations regarding the effect of stimulus form and depth of encoding on identification and cued recall of environmental sounds. First, we expected little or no cross-form priming (i.e., from the name-only conditions) in both encoding conditions. Second, if priming in the sound identification is mediated primarily by perceptual processes, then performance following nonsemantic encoding should be at least as high as performance following semantic encoding. Under explicit memory instructions, however, sound cued recall should be lower after nonsemantic encoding than after semantic encoding. Consistent with this assumption, previous studies have found higher levels of free recall of a categorized list of environmental sounds after semantic encoding than after nonsemantic encoding (e.g., Ferrara, Puff, Giola, & Richards, 1978). Third, we expected levels of explicit cued recall to be higher in the name-and-sound conditions than in the name-only conditions. Relevant data have been provided by Bartlett (1977), who compared free recall, recognition, and cued recall of environmental sounds under name-and-sound and name-only conditions. Whereas free recall for the name-only group and the name-and-sound group were the same, the name-only group was worse than the name-and-sound group in both sound cued recall and sound recognition. These data imply that stimulus form affects critically performance on explicit memory tests in which the retrieval cues are perceptually related to the encoded materials (e.g., also see Weldon et al., 1995, for similar findings with visual nonverbal tests). In contrast, such effects are minimal on explicit memory tests like free recall that rely primarily on conceptual information.

### *Method*

*Subjects.* Forty-eight Harvard undergraduate students participated in the experiment in exchange for a $5 payment. They were randomly assigned to experimental conditions.

*Materials, design, and procedure.* The design was 3 × 2 × 2 mixed factorial, with encoding task (semantic vs. nonsemantic) and test (sound stem identification vs. sound stem cued recall) as between-subject factors and stimulus form (name-and-sound vs. name-only vs. nonstudied) as the within-subject factor.

Target materials consisted of sounds drawn from a variety of sound effect compact discs (the source list can be obtained from the authors). All the sounds were recordings of real life events (e.g., "toilet flushing," "ping-pong game," "door knock," etc.). No animal sound or musical sound was included in this set. Four human sounds (i.e., sneezing, snoring, kissing, and belching) were used as practice and filler items, but they were not included in the critical set. Each sound was digitized into the Apple Macintosh computer by the SoundEdit software at a sampling rate of 22 kHz. From each sound a 5-s segment relatively free of long pauses and background noise was selected. The first 1-s segment of each 5-s segment served as the sound stems. The loudness of each sound was individually adjusted such that the perceived volume was roughly the same across all sounds. All sounds were audible at a comfortable level in a sound-attenuated room when the volume of the speaker of the Macintosh computer set at level three. A number of the sounds were passed through a low pass filter (20 dB attenuation) with a cutoff frequency at 8 kHz in an attempt to improve sound quality.

A separate pilot study was conducted to obtain norms regarding the identifiability for these sounds. Nineteen subjects heard a long list of sounds twice and attempted to identify with a short phrase the identity of each test sound by giving the first response that came to mind. In the first pass, all sounds were presented in their 1-s sound stem form; in the second pass, all sounds were presented in their 5-s form. Sounds were presented in different random orders during the two passes. There was no limit on response time. After each sound was presented, subjects wrote down on response sheets their corresponding identification response. Descriptions of a sound synonymous to the designated name of the sound (i.e., the name on the original sound effect CDs from which the sound was drawn) were accepted as correct. Twenty-four critical sounds (see Appendix) were thus selected with mean identification accuracy at 40.2% (range = 5 to 73.7%; *SD* = 25%) for the 1-s version and 85.5% (range = 52.6 to 100%; *SD* = 21.4%) for the 5-s version. These 24 sounds satisfied the further restriction that they did not share closely related names with one another. This 24-item list was further divided into three 8-item sublists matched for mean identification accuracy to serve in the three within-subject conditions. Across subjects, each sublist appeared equally often in each within-subject condition according to a Latin square design.

All subjects were tested individually in sound-attenuated testing rooms. Subjects were informed at the beginning of the study phase that stimuli would be presented in one of two forms. Visual presentation of each name on the computer for 2 s preceded either a 5-s sound segment (i.e., name-and-sound condition) or a 5-s blank screen (i.e., name-only condition). Half of the subjects were given semantic encoding instructions. For each stimulus presented, these subjects rated on a 3-point scale (1 = rarely; 2 = sometimes; 3 = frequently) how frequently they encountered the event described by the name in everyday life. The other half of the subjects were given nonsemantic encoding instructions. They were asked to perform a pitch judgment task as follows. If a particular stimulus was presented as name-and-sound, subjects were to observe the pitch profile of the whole sound segment and rate on a scale of 1 to 3 whether it was going up or down in pitch (1 = pitch goes up from beginning to end; 2 = pitch stays roughly the same throughout; 3 = pitch goes down from beginning to end). If the stimulus was presented as name-only, subjects were to imagine the verbal phrase being spoken aloud and to apply the 3-point pitch rating to it. This was done to minimize the possibility of subjects spontaneously forming an auditory image of the referent sound.

The study list consisted of 16 critical items randomly intermixed, preceded by 2 primacy items and followed by 2 recency items. After exposure to each stimulus item, subjects responded by pressing the appropriate key on the keyboard. No mention of the later memory test was made at the time. No time limit for responding was imposed. After all 20 sounds were presented, subjects engaged in a filler task in which they had to answer general knowledge questions for 5 min.

After the filled delay, subjects were given either a sound stem identification or a sound stem cued recall test. Subjects in the identification group were told that they would hear a series of brief sounds of 1 s each and that their task was to identify them. These subjects were further informed that although some of the sound stems might be very similar to what they heard earlier in the experiment, they should focus on the present task and always try to identify the sound stems by giving the very first response that came to mind. Subjects in the cued recall group were told that they would hear a series of brief sounds of 1 s each, and their task was to use these brief sounds as cues to help them recall stimuli they encountered in the study phase.

For these subjects it was emphasized that they should respond only if they were quite sure they encountered the stimulus event previously, and guessing was discouraged. Subjects were provided with a response sheet containing numbered blanks for them to write down their responses. Each trial was initiated by a press on the space bar. Then a 1-s sound was immediately presented. As soon as subjects were ready to respond, they pressed the space bar once (i.e., to record their reaction time) and then wrote down their response in the space provided on the response sheet. Subjects were given a total of 36 trials. The first 2 were practice trials and were immediately followed by 2 buffer trials. The target list of 32 items then followed, consisting of 24 critical items (16 old, 8 new) plus another 8 filler sounds intermixed in a predetermined random order. The filler sounds had not been presented in earlier parts of the experiment, making the ratio of studied to nonstudied items on the target list one to one. The target list was presented in one predetermined random order for one half of the subjects in each experimental condition and another for the other half of the subjects.

For the subjects in the cued recall group, we imposed a further source judgment requirement for them to identify the original form in which the particular stimulus was presented. Whenever subjects gave a recall response, they were to write either a *N* if they remembered seeing only the name of the cue sound earlier or a *S* if they remembered getting both the sound and the name earlier.

After the experiment was over, subjects were given a questionnaire to assess the extent to which they followed instructions and whether they engaged in intentional explicit memory strategies in performing the sound stem identification test in particular. Four subjects in the sound stem identification group who were identified by this questionnaire as using explicit recall strategies were replaced.

### *Results and Discussion*

Responses were scored as correct when they were synonymous with the designated name, following Bartlett (1977) and others. We scored the data in different ways that were either more lenient or more strict with respect to the synonymity requirement, but they all led to identical results. Therefore, we shall only present the results using the standard scoring criterion in this article. We have also performed analyses of the error patterns as well as reaction time as a function of experimental conditions, but because these analyses do not lead to conclusions different from that derived from the analyses of accuracy data they will not be discussed further.

Table 1 presents the mean proportion of correct responses as a function of stimulus form, encoding task, and test.

*Sound stem identification test.* A 3 × 2 split-plot ANOVA with stimulus form (name-and-sound vs. name-only vs. nonstudied) as a within-subject factor and encoding task (semantic vs. nonsemantic) as a between-subject factor indicated that only the main effect of stimulus form was significant, $F(2, 44) = 36.9$, $MSE = .021$, $p = .0001$. Neither the main effect of encoding task, $F(1, 22) = 1.58$, $MSE = .023$, $p = .20$ nor its interaction with stimulus form, $F(2, 44) = .67$, $MSE = .021$, $p = .52$ was significant. We performed focused a priori comparisons to test for priming in individual conditions. Because we were interested in all pairwise comparisons

TABLE 1
Mean Proportion of Correct Responses as a Function of Encoding Tasks, Stimulus Form, and Test Instructions in Experiment 1

| | Encoding task | | | | | |
|---|---|---|---|---|---|---|
| | Nonsemantic | | | Semantic | | |
| Test | Name-and-sound | Name-only | Nonstudied | Name-and-sound | Name-only | Nonstudied |
| Implicit | .71 (.12) | .33 (.20) | .40 (.18) | .71 (.14) | .44 (.11) | .43 (.10) |
| Explicit | .76 (.25) | .38 (.21) | .03 (.06) | .83 (.17) | .41 (.18) | .01 (.04) |

*Note.* Numbers in parenthesis are standard deviations.

of the three within-subject conditions, we applied Dunn's multiple *t* test procedure for three specific contrasts. This procedure calls for a Bonferroni adjustment for each *t* test performed to control the experimentwise error rate at .05. For subjects in the nonsemantic encoding group, priming was significant in the name-and-sound conditions, $t(11) = 5.24$, $MSE = .021$, adjusted $p = .0003$, but not in the name-only condition, $t(11) = -1.18$, $MSE = .021$, adjusted $p = .389$. Results for the semantic group were similar, with significant priming in the name-and-sound condition, $t(11) = 4.75$, $MSE = .021$, $p < .01$ for but not in the name-only condition, $t(11) = .19$, $MSE = .021$.

The statistical analyses above confirmed our predictions that (a) there was no cross-form priming on the sound stem identification test, regardless of prior encoding operations, and (b) priming was highly significant following exposure to the environmental sounds and occurred independently of type of encoding operations. These findings extend previous findings that nonverbal perceptual implicit tasks show no cross-form priming to the domain of environmental sounds. Moreover, our finding that priming of sound stem identification was insensitive to depth of encoding is consistent with previous findings in the literature that perceptual implicit tests tend to be little affected by depth of processing.

One point about the data deserves further comment. Table 1 indicates that the mean proportion of sound stems identified as 0.33 for the nonsemantic, name-only condition and 0.44 for the semantic, name-only condition. These results seem to suggest that semantic encoding boosted performance in the cross-form conditions, which is consistent with the idea that cross-form priming is semantic in nature. However, the data should be interpreted with caution for a number of reasons. First, identification of nonstudied sounds was also numerically lower in the nonsemantic group (0.40) than in the semantic group (0.43). Second, identification performance in the nonsemantic, name-only condition (0.33) is numerically *lower* than the corresponding baseline (0.40), which probably represents random fluctuations. Third, even though Experiment 1 has relatively limited experimental power, performance in the name-only condition for both groups did not differ significantly from the respective baselines.

*Sound stem cued recall test.* The cued recall data could be scored in one of two ways. A more lenient criterion would count a response as correct regardless of the accompanying source judgment (whether the item was presented as name-only (*N*) or name-and-sound (*S*) during encoding). A stricter criterion would count a response as correct only if the accompanying source judgment was also correct. The pattern of results, however, remained the same whichever scoring criterion we adopted, and so we shall present the results with the more lenient criterion.

The nonstudied baseline was subtracted from each corresponding experimental condition to yield an adjusted recall score. A 2 × 2 split-plot ANOVA with stimulus form as the within-subject factor and encoding task as the between-subject factor revealed that cued recall in the name-and-sound condition was higher than that in the name-only condition, $F(1, 22) = 63.5$, $MSE = .03$, $p < .0001$. Although recall after semantic encoding (mean = .651) was numerically higher than that after nonsemantic encoding (mean = .536), the main effect of encoding task turned out not to be significant, $F(1, 22) = 1.22$, $MSE = .06$, $p = .28$. The interaction of encoding task and stimulus-form was also not significant, $F(1, 22) = .10$, $MSE = .03$, $p = .76$.

Because we did not find a dissociation between implicit and explicit tests, one might wonder whether the results we observed on the identification test actually reflected implicit memory. However, priming was consistently absent in the cross-form conditions in both implicit memory groups, whereas cross-form cued recall was consistently above the nonstudied rate in both explicit memory groups. If subjects had been engaging in intentional retrieval, then we would expect sound stem identification performance in the cross-form condition to be higher than nonstudied baseline. Because this outcome was not observed, there are reasons to believe that performance on our implicit memory test has not been contaminated by explicit retrieval (see McDermott & Roediger, 1994, and Rajaram & Roediger, 1993, for this argument).

Our findings of higher levels of cued recall in the name-and-sound condition than the name-only condition is consistent with earlier findings (e.g., Bartlett, 1977), suggesting a perceptual component on this explicit memory test. It also provides support for recent proposals that explicit recall given retrieval cues that were perceptually related to the studied materials might be mediated by a two-stage generation-recognition processes (e.g., see Jacoby & Hollingshead, 1990; and Roediger et al., 1992, for a discussion of this idea). For instance, in sound stem cued recall, subjects may have to first identify the briefly presented sound stem and then attempt to recognize it as having occurred earlier during encoding. Presumably, the first stage of identification in this two-stage process is functionally similar to sound stem identification, given that the retrieval cues are the same in both cases. To the extent that priming was affected by the variable of stimulus form change, sound stem cued recall should also be affected in the same direction by this variable.

On the other hand, although recall in the semantic condition was higher than that in the nonsemantic condition in numerical terms, it is surprising that we did not find a significant depth of encoding effect. Given the relatively small number of subjects in each between-subject condition ($N = 12$), and the fact that depth of encoding was manipulated on a between-subject basis, we may have lacked adequate power to detect significant effects. We addressed this issue in Experiment 2.

## EXPERIMENT 2

In Experiment 2, we simplified the design and focused on the name-and-sound condition, with the name-only condition dropped, thereby allowing us to increase the number of subjects ($N = 18$) per condition. We also manipulated depth of processing as a within-subject factor to further increase experimental power.

### *Method*

*Subjects.* Thirty-six Harvard undergraduate students participated in the experiment in exchange for a $5 payment. Three subjects in the implicit memory group reported that they engaged in explicit memory retrieval during testing and were subsequently replaced.

*Design and procedure.* The design was a 3 × 2 mixed factorial, with test instructions (implicit vs. explicit) as the between-subject factor and encoding conditions (nonsemantic vs. semantic vs. nonstudied) as the within-subject factor. For the semantic task subjects rated on a 3-point scale whether the event described by the name occurred rarely (1), sometimes (2), or frequently (3) in their recent past. For the nonsemantic task subjects rated on a 3-point scale whether the overall pitch of the environmental sound was lower than, the same as, or higher than the pitch of their own voice when they were saying the sentence ''My name is XXX'' (1 = higher, 2 = same, 3 = lower). We simplified the nonsemantic task because a handful of subjects reported difficulty in performing the previous version used in Experiment 1.

The structure of the experiment was essentially the same as Experiment 1, with a few details of the study phase modified. All stimuli were now presented in the form of name-and-sound, and subjects in the cued recall group were not required to perform the source judgment. Across subjects, each item appeared equally often in the nonsemantic, semantic, and nonstudied encoding conditions. Items from the semantic and nonsemantic conditions were randomly intermixed to form the critical 16-item study list. Each trial in the study phase consisted of the following presented in order: (a) A cue for encoding on the computer screen for 2 s (''Next Stimulus: Pitch Judgment'' or ''Next Stimulus: Frequency Judgment''), (b) the name of the sound on the screen for 2 s, (c) the 5-s environmental sound, and (d) a 3-point scale appropriate to the particular encoding condition. The study list was 20 items long just as in Experiment 2. The rest of the procedure was identical to Experiment 1.

### *Results and Discussion*

We assessed the validity of the modified nonsemantic encoding task by asking the subjects, both before the study list was presented and when the experiment was over, whether they had any difficulty in understanding the instructions. All subjects indicated that they performed the task without any difficulty.

Table 2 presents the mean proportion of correct responses in Experiment 2 as a function of encoding conditions and type of test. Using Dunn's multiple $t$ test procedure for three specific contrasts, sound stem identification was found to be significantly enhanced relative to baseline after both semantic encoding, $t(17) = 5.02$, $MSE = .026$, Bonferroni adjusted $p < .0002$, and nonsemantic encoding, $t(17) = 6.51$, $MSE = .026$, adjusted $p < .0001$. Performance in the nonsemantic encoding condition was numerically higher than that in the semantic encoding condition, but this effect was not significant, $t(17) = 1.488$, $MSE = .026$, adjusted $p = .23$. For the explicit memory conditions, recall after semantic encoding was significantly higher than that

TABLE 2
Mean Proportion of Correct Responses as a Function of Encoding Tasks and Test Instructions in Experiments 2 and 3

| | Encoding conditions | | |
|---|---|---|---|
| | Nonsemantic | Semantic | New |
| Expt 2—Name-and-sound | | | |
| Implicit test | .76 (.10) | .68 (.16) | .41 (.21) |
| Explicit test | .69 (.20) | .83 (.14) | .01 (.03) |
| Expt 3—Name-only | | | |
| Implicit test | .47 (.17) | .42 (.17) | .40 (.18) |
| Explicit test | .28 (.13) | .51 (.17) | .01 (.04) |

*Note.* Numbers in parenthesis are standard deviations.

after nonsemantic encoding, $t(17) = 2.83$, $MSE = .022$, adjusted $p = .017$, which was in turn higher than the nonstudied condition, $t(17) = 13.8$, $MSE = .022$, adjusted $p < .0001$. An additional 2 × 2 ANOVA with the encoding task as the within-subject factor, type of tests as the between-subject factor, and adjusted scores (studied–nonstudied) as the response measure confirmed the above findings: the two-way interaction effect was significant, $F(1, 34) = 14.3$, $MSE = .016$, $p = .0006$, and so was the effect of test type, $F(1, 34) = 42.9$, $MSE = .08$, $p < .0001$. The effect of encoding was not significant, $F(1, 34) = .89$, $MSE = .16$.

The observed interaction between encoding task and type of test is important because subjects in both groups studied exactly the same items and were given exactly the same retrieval cues; the only difference was the retrieval instructions given to them at test. To the extent that a dissociation can be found, the nature of the implicit and explicit tasks we used conform to the retrieval intentionality criterion (Schacter, Bowers, & Booker, 1989). Results from Experiment 2 show that priming for auditory nonverbal information can be dissociated from explicit memory as a function of the manner in which the stimuli are originally encoded. Previous observations have shown that semantic encoding differentially improves explicit memory as compared to priming (e.g., Graf & Mandler, 1984; Jacoby & Dallas, 1981; Roediger et al., 1992; Schacter & Church, 1992). Our results extend these findings into the auditory nonverbal domain and provide further support for the idea that priming in identification of environmental sounds depends primarily on perceptual processes independent of those supporting explicit memory.

## EXPERIMENT 3

Even though we observed a dissociation between implicit and explicit memory in Experiment 2, one might still question whether this dissociation is attributable to the effects of the verbal coding alone rather than to the effects of the environmental sounds per se. For instance, if we suppose that presentation of the sound names automatically leads to a certain amount of semantic processing that benefits subsequent sound identification, then the presence of the sound names in the nonsemantic encoding condition might have turned it into a semantic encoding condition. This could presumably reduce the difference between the two encoding conditions and as a result lead to equivalent levels of priming. However, there are at least two points against this alternative explanation. First, subjects in the implicit and explicit memory conditions were treated identically up to the point of the memory test. If presentation of verbal labels somehow made the two encoding conditions functionally equivalent, then there should have been no differences between the encoding conditions on the explicit memory test. But this is not what we found. Second, there is no evidence whatsoever from Experiment 1 to suggest that the sound names lead to any priming at all by themselves given either type of encoding.

Nevertheless, it is still important to examine further the issue of cross-form priming. The name-only conditions in Experiment 1 consisted of visual presentation of the sound names without any auditory input, whereas in Experiment 2 subjects were always given auditory input (i.e., the environmental sounds) in addition to visual presentation of the names. It is conceivable that auditory presentation of the sound names might be sufficient for subsequent cross-form priming to occur. In addition, although the semantic encoding task stayed the same between Experiments 1 and 2, the nonsemantic task in Experiment 2 (i.e., compare the pitch of environmental sound to one's own voice) was different from that used in Experiment 1 (i.e., judge whether a sound is rising or falling in pitch). It is at least conceivable that this modified encoding task might lead to some cross-form priming. Finally, our finding of no cross-form priming is based on a failure to reject the null hypothesis and hence should not be too readily accepted.

Experiment 3 addressed these issues by examining whether auditory presentation of sound names alone produces significant priming. Because of the item-to-item variability in pitch inherent in the set of environmental sounds we used, we also introduced item-to-item variability in pitch into the set of spoken names by having a different speaker say each sound name. The nonsemantic (i.e., pitch comparison) encoding task in Experiment 3 required subjects to compare the pitch of the voice of the speaker who presented the sound name to the pitch of their own voice. The semantic encoding task was the same as in Experiment 2. Otherwise the design of Experiment 3 was the same as that in Experiment 2.

### *Method*

*Subjects.* Thirty-six Harvard undergraduate students participated in the experiment in exchange for a $6 payment. Three subjects in the implicit memory group reported that they engaged in explicit memory retrieval during testing and were subsequently replaced.

*Design and procedure.* The design was a 3 × 2 mixed factorial, with tests instructions (implicit vs. explicit) as the between-subject factor and encoding conditions (nonsemantic vs. semantic vs. nonstudied) as the within-subject factor, as in Experiment 2.

The structure of the experiment differed from that in Experiment 2 in only one respect. All stimuli were now presented in the name-only form, first visually and then auditorily. Each trial in the study phase consisted of the following presented in order: (a) A cue for encoding on the computer screen for 2 s (''Next Stimulus: Pitch

Judgment'' or ''Next Stimulus: Frequency Judgment''), (b) the name of the sound visually on the screen for 2 s, (c) the name of the sound auditorily through the built-in loudspeaker of the computer, and (d) the corresponding 3-point rating scale. In the case of the pitch comparison task, subjects were to compare the pitch of the voice of the speaker who presented the sound name to the pitch of their own voice (1 = pitch of speaker's voice lower than theirs; 2 = roughly the same; 3 = pitch of speaker's voice higher than theirs).

Each of the 24 sound names was paired with a different speaker. All of the speakers were instructed to enunciate the sound names clearly in normal speech rate. The sound names were digitized in SoundEdit with a sampling rate of 22 kHz. Of the 8 sound names presented in each within-subject condition during encoding, half were presented by 4 different female speakers and half by 4 different male speakers. There was moderate variability in age range for the speakers (female: 20–35; male: 21–34) as well as perceived pitch range in the speakers' voice.

### *Results and Discussion*

Table 2 presents the mean proportion of correct responses in Experiment 3 as a function of encoding conditions and type of test. Again Dunn's multiple $t$ test procedure was used with the experimentwise error rate controlled at .05. There was no evidence of significant priming in either the nonsemantic encoding condition, $t(17) = 1.365$, $MSE = .023$, adjusted $p = .285$, or the semantic encoding condition, $t(17) = .415 < 1$, $MSE = .023$. Sound stem identification performance in the nonsemantic and in the semantic encoding condition were not different from each other, $t(17) = .95 < 1$, $MSE = .023$. For the explicit memory conditions, recall following semantic encoding was significantly higher than that following nonsemantic encoding, $t(17) = 5.27$, $MSE = .017$, adjusted $p < 0.001$, which was in turn higher than the nonstudied condition, $t(17) = 6.24$, $MSE = .022$, adjusted $p < .0001$. An additional $2 \times 2$ ANOVA with encoding task as within-subject factor, type of test as between-subject factor, and adjusted score (studied–nonstudied) as response measure revealed a significant interaction effect, $F(1, 34) = 16.3$, $MSE = .021$, $p = .0003$, a significant encoding task effect, $F(1, 34) = 36.8$, $MSE = .057$, $p < .0001$, as well as a significant type of test effect, $F(1, 34) = 6.9$, $MSE = .021$, $p < .013$, thus confirming the analyses above.

Despite variations in procedural details, the above findings replicate the basic findings in Experiment 1 and provide further support for the claim that the mere presence of the sound names is not sufficient to lead to any subsequent cross-form priming. Experiments 2 and 3 were identical in overall design, procedural arrangement, and even the number of subjects run, and yet we found substantial priming in Experiment 2 but not Experiment 3. The results of Experiments 1 and 3 suggest that neither visual nor auditory presentation of the sound names is adequate for any subsequent cross-form priming to occur. It follows that the priming result in Experiment 2 is not attributable to the sound names and that the presence of the environmental sounds is necessary for priming on the sound stem identification task.

In contrast to priming, both conceptual and perceptual factors seem to affect sound cued recall. The depth of encoding effect found in both Experiments 2 and 3 points to the involvement of semantic processing in recall, whereas the lower levels of cued recall in the cross-form conditions relative to their same-form controls indicate a role for perceptual processing. These results can be explained by the generation/recognition model first put forward by Jacoby and Hollingshead (1990), which we have alluded to earlier. If sound stem cued recall can be broken down into two successive component processes, namely, sound identification and recognition, then one would expect that variables that have an effect on priming (e.g., change in stimulus form) would have a similar effect on cued recall. In contrast, a variable that primarily affects recognition but leaves priming relatively unaffected (e.g., depth of encoding) would influence sound stem cued recall but not sound stem identification. Our data agree well with those previously reported in the literature (e.g., Jacoby & Hollingshead, 1990; Roediger et al., 1992).

One final point deserves further comment. If we assume that the same-form priming found in Experiment 2 is perceptual in nature, and cross-form priming in general is semantic in nature, then we would expect (a) same-form priming to be independent of encoding operations, which is what we found in Experiment 2; and (b) semantic encoding to produce more cross-form priming than nonsemantic encoding, which is not what we found in Experiment 3. However, the critical point to note is that there was *no* cross-form priming in Experiment 3 at all. In fact, the one condition in which there was a numerical trend toward positive cross-form priming (0.47 vs. 0.40) was a perceptual encoding condition (i.e., pitch comparison). Indeed, semantic encoding produced no cross-form priming in either Experiment 1 (priming = .01) or Experiment 3 (priming = .02). This fact should prompt us to reconsider the notion that cross-form priming is necessarily semantic in nature.

## GENERAL DISCUSSION

This research has documented a new phenomenon—priming of environmental sounds—and described two of its characteristics. Data from Experiments 1 and 3 indicate that encoding the sound names by themselves does not lead to long-term repetition priming, whereas encoding the names and the sounds together does lead to priming regardless of the particular encoding conditions. This result supports the notion that priming in environmental sound identification is mediated by perceptual processes that are independent of explicit memory. It also supports the hypothesis that priming does not transfer across perceptual form on auditory nonverbal implicit tests, as has previously been observed on visual tests. And whereas explicit memory benefited from prior semantic encoding relative to nonsemantic encoding, priming was insensitive to such manipulations. These experiments provide converging evidence that priming of environmental sound identification is mediated primarily by perceptual processes, generated within what we have called the perceptual representation system, or PRS (Schacter, 1994; Tulving & Schacter, 1990).

Previous research (e.g., Ballas, 1993; Ballas & Mullins, 1991; Howard & Ballas, 1980) has shown that context and other situational cues have an effect on environmental sound identification. It is at least conceivable that we have in some way altered the ''natural'' process of sound identification by placing subjects in a sound-attenuated room to identify singly presented sounds without other cues in the environment.

However, our focus on the perceptual aspects of environmental sound identification should not be taken to mean that we believe context or subjects' expectation play no role in sound identification. We do believe, however, that eliminating context and other environmental cues should remove only higher-order semantic or conceptual information without altering substantially the perceptual process of sound identification itself. This latter claim is of course open to further empirical investigations.

One might also question whether the priming effect we observed is indeed perceptual or whether it represents learning of associations between the environmental sounds and their names. Priming could then be viewed not as a facilitation in perceptual identification of a degraded sound cue, but as a facilitation in producing the appropriate verbal name to the sound counterpart with which it was previously paired. Although our data do not rule out this alternative explanation definitively, three points argue against this interpretation. First, neither of our encoding tasks specifically required subjects to form associations between the name and the sound. In fact, data from our norming study show that across all items subjects spontaneously generate the designated names for the 5-s environmental sounds 85% of the time, suggesting that the names and the sounds are already strongly associated. Second, subjects at the time of the priming test are presented with perceptually degraded sound cues. Logically, it seems impossible to know what name has been previously associated to the sound stem before the subject recovers from the perceptually degraded cue a more redintegrated version of the sound. That process of redintegration, we would argue, is largely perceptual in nature and is a prerequisite to any subsequent associative processes. Third, in most experimental paradigms to date examining visual nonverbal priming for familiar objects, it is standard practice to use naming or identification as an encoding task (e.g., Jacoby, Baker, & Brooks, 1989; Jolicoeur & Milliken, 1989; Snodgrass & Feenan, 1990; Srinivas, 1993) or explicitly provide the appropriate names before or during encoding (e.g., Biederman & Cooper, 1991a, 1991b, 1992; Srinivas, 1993). The general assumption is that priming in these paradigms reflects enhanced perceptual analyses of the stimuli rather than strengthening the association between the stimuli and their names. There is as yet no compelling reason for us to depart from that general assumption. All in all, the points above argue against a relatively straightforward associative account of priming. Whether a more sophisticated version of the associative account can handle these criticisms remains to be seen.

Our results extend previous findings in the visual domain that priming does not transfer across perceptual form on nonverbal tests. The consistent absence of cross-form priming, together with the frequent presence of cross-modal priming on many completion and identification tasks, presents a challenge to theoretical accounts of perceptual priming. At present, accounts that attribute transfer across surface form variations exclusively to explicit memory contamination (e.g., Jacoby et al., 1993) or involvement of semantic processes (e.g., Hirshman et al., 1990; Masson & MacLeod, 1992; Toth & Hunt, 1990) do not explain satisfactorily why there should be a systematic difference between priming across modality and priming across perceptual form. Nor do these accounts explain adequately why semantic encoding does not enhance cross-modal priming relative to nonsemantic encoding (e.g., Craik et al., 1994; Kirsner, Milech, & Standen, 1983; Roediger et al., 1992; Srinivas & Roediger, 1990; Weldon, 1993). In contrast, the mental translation hypothesis (e.g., McDemott & Roediger, 1994) suggests that cross-modal and cross-form priming depends entirely on the extent to which subjects overtly or covertly translate the study stimuli into forms appropriate to the subsequent test. For instance, McDermott and Roediger (1994) had subjects studied printed words and found cross-form priming in a subsequent picture fragment identification test if and only if subjects were instructed to form images of the corresponding pictures at study. Similarly, subjects who studied pictures showed cross-form transfer on a word fragment completion test if and only if they imagined the corresponding words at study. With respect to environmental sound identification, one would expect, by extension, auditory imagery to prime subsequent sound identification. Preliminary results from our laboratory suggest that this is indeed the case. On the other hand, it is unclear why cross-modal priming is consistently observed even in the absence of explicit imagery instructions during encoding. Moreover, some researchers have failed to obtain an effect of imagery on cross-modal priming (e.g., Donnelly, 1988). Further research is required to settle the issue.

Finally, it should be noted that our findings do not support conclusively the hypothesis that no cross-form priming will be observed in all nonverbal implicit tests. It is conceivable that priming transfers more consistently across sensory modality in the nonverbal domain (i.e., between pictures and sounds), just as it does in the verbal domain. Would subjects show priming in sound identification more readily if they studied pictures depicting the relevant events at study? And if so, does such cross-modal priming depend on appropriate imaginal encoding? Further study of implicit memory for environmental sounds provides a potentially useful window on these unanswered questions about the nature of perceptual priming.

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## APPENDIX:
## ENVIRONMENTAL SOUNDS USED IN THE EXPERIMENTS

| Descriptions | Sound name | 5 s (%) | 1 s (%) |
|---|---|---|---|
| Helicopter hovering | Helicopter | 100 | 74 |
| Donkey Kong in progress | Videogame | 100 | 53 |
| Clock ticking | Clock ticking | 100 | 47 |
| Brushing teeth | Brushing teeth | 79 | 42 |
| Machine gun firing | Machine gun | 95 | 32 |
| Squeaky gate slowly closing | Squeaky gate | 63 | 5 |
| ThunderStorm | Thunder | 53 | 38 |
| Rolling dice | Rolling dice | 53 | 16 |
| Flushing toilet | Toilet flushing | 95 | 63 |
| Sharpening a knife | Knife sharpening | 74 | 53 |
| A couple of car horns | Car horns | 95 | 68 |
| Coins dropped into a glass | Coins jingling | 84 | 63 |
| Shuffling a deck of cards | Shuffling cards | 53 | 21 |
| Kettle begins to whistle | Kettle boiling | 68 | 5 |
| One person's footsteps | Footsteps | 68 | 11 |
| Ping-Pong game in progress | Ping-Pong game | 84 | 21 |
| A couple of knocks on door | Knocking on door | 89 | 63 |
| Wood being sawed | Sawing wood | 89 | 58 |
| Dot-matrix printer printing | Printer printing | 100 | 58 |
| Sweeping broken glass/dishes | Sweeping broken glasses | 84 | 63 |
| Stapler stapling | Stapler stapling | 53 | 5 |
| Start-up vacuuming and sucking | Vacuum cleaning floor | 53 | 37 |
| Dialing rotary phone | Dialing rotary phone | 100 | 5 |
| Clings from wind chimes | Wind chimes | 89 | 16 |

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