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Lateralization of Lexical Codes in Auditory Word Recognition

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Three experiments examined the lateralization of lexical codes in auditory word recognition. In Experiment 1 a word rhyming with a binaurally presented cue word was detected faster when the cue and target were spelled similarly than when they were spelled differently. This orthography effect was larger when the target was presented to the right ear than when it was presented to the left ear. Experiment 2 replicated the interaction between ear of presentation and orthography effect when the cue and target were spoken in different voices. In Experiment 3, subjects made lexical decisions to pairs of stimuli presented to the left or the right ear. Lexical decision times and the amount of facilitation which obtained when the target stimuli were semantically related words did not differ as a function of ear of presentation. The results suggest that the semantic, phonological, and orthographic codes for a word are represented in each hemisphere; however, orthographic and phonological representations are integrated only in the left hemisphere. © 1986 Academic Press, Inc.

A number of recent studies have provided convincing evidence that visually based codes for words are rapidly and automatically accessed

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during auditory word recognition. Many of these studies have found orthographic effects on making rhyme judgments to spoken words. Seidenberg and Tanenhaus (1979) first reported this effect in an experiment in which subjects monitored short lists of spoken words for a word which rhymed with a cue word, also presented auditorily. Rhyme words which were spelled similarly to the cue word (e.g., bite–kite) were detected more rapidly than rhymes which were spelled differently (e.g., bite–fight). Seidenberg and Tanenhaus also presented pairs of words in a rhyme–nonrhyme decision task. Rhyming pairs were judged to be rhymes more rapidly when they were spelled alike than when they were spelled differently. In contrast, nonrhymes which were spelled alike (e.g., touch–couch) took longer to be judged as nonrhymes than phonemically matched controls which were orthographically less similar (e.g., dutch–couch). These results have since been replicated and extended. Donnenwerth-Nolan, Tanenhaus, and Seidenberg (1981) noticed a production frequency bias in favor of orthographically similar rhymes in the materials used by Seidenberg and Tanenhaus. However, they replicated the finding that orthographically dissimilar rhymes are more difficult to detect than orthographically similar rhymes when production frequency was equated. Zecker and Herrmann (1983) repeated the Seidenberg and Tanenhaus (1979) rhyme–nonrhyme experiment using visually similar and dissimilar letter pairs instead of words, with visual similarity measured by a visual confusion matrix. The results with letters paralleled the results with words: Visual similarity facilitated rhyme decisions and interfered with nonrhyme decisions. Zecker and Zinner (1982) have demonstrated that spelling effects in rhyme monitoring are larger with children who are good readers than children who are poor readers.

Orthographic effects in spoken word recognition have also been demonstrated in a range of tasks other than rhyme detection. Tanenhaus, Flanigan, and Seidenberg (1980) found that color-naming latencies to a visually presented target were interfered with when the word was preceded by a spoken word which was visually similar (e.g., touch–couch). Jakimik, Cole, and Rudnicky (1980) reported that making auditory lexical decisions to *wreak* facilitated lexical decisions to *wreakage* but not to *record*. Campbell (1983) investigated the effects of a spoken word on subjects' spelling of a subsequently presented nonword with several possible spellings and found that the spelling of the word strongly influenced the spelling of the nonword. Ehri (1980) has conducted a number of studies which demonstrate that children learn spoken nonwords more rapidly as responses when they are given the correct spelling of the nonsense word as a study aid.

The studies reviewed above clearly establish that visually based codes for words are accessed in auditory word recognition in a range of tasks, each of which could, in principle, be performed without accessing visually based information. Thus it appears that the orthographic representation of a word or a letter becomes available as an automatic consequence of the word recognition process. Coupled with the well-established complementary finding that speech-based codes are accessed in visual word recognition (see McCusker, Hillinger, & Bias, 1981, for a recent review) these results demonstrate that multiple codes for words are typically made available during word recognition. Multiple code access presumably occurs because the orthographic and phonological codes for words become closely integrated as the child learns to read (Ehri, 1980).

The present studies examined the lateralization of orthographic effects in auditory word recognition to investigate whether orthographic and phonological codes are represented differently in the right and left hemispheres. Orthographic and phonological codes are clearly integrated in the left hemisphere, allowing for rapid spelling-to-sound and sound-to-spelling mapping. However, the situation is less clear for the right hemisphere. There is an increasing amount of evidence that lexical codes are represented in the right hemisphere (Zaidel, 1973, 1978, 1981). The right hemisphere can recognize both spoken and written words and there is some evidence that concrete words and automatic phrases can be recognized as rapidly in the right hemisphere as in the left hemisphere (Zaidel, 1973; van Lancker, 1975). In fact, the spoken word vocabularies of the two hemispheres have been found to be approximately equivalent, although the left hemisphere has a considerably larger vocabulary (Zaidel, 1978, 1981). There is, however, some question about whether the right hemisphere can make rhyme decisions. In studies with split brain patients, Levy and Trevarthen (1973) and Levy (1974) found that the right hemisphere could not judge which picture rhymed with a printed word. Zaidel and Peters (1981) reported similar results with two split-brain patients; however, one patient was able to perform above chance on a task which required matching two pictures with homonymous or rhyming names. This occurred despite the patient's inability to name either picture. Zaidel and Peters suggested that this patient was making rhyme decisions based on an "auditory image" rather than a phonological code. Supporting evidence that the right hemisphere has difficulty with rhyme judgments comes from studies by Vaid (1983), who found that with tachistoscopic presentation there was a right hemisphere advantage for rhyme judgments when rhyming pairs of words were spelled alike. However, when a mixture of similarly and dissimilarly spelled rhymes was used, a large left hemisphere advantage obtained, suggesting that the right hemisphere was using a visual matching strategy to make "rhyme" judgments. Similar results have recently been reported by Caramazza, Berndt, and Basili (1983), who found that an aphasic patient with severe left hemisphere damage used a visual matching strategy in choosing which pseudohomophone rhymed with a word. When the stimuli were controlled to prevent a visual similarity strategy from being effective, their subject's performance dropped to chance levels.

In all the studies reviewed above, subjects were asked to make a rhyme decision to a visually presented word or letter string. Thus, prior to making a rhyme decision the subject would have to use an orthographic representation to retrieve or compute a phonological representation. If the right hemisphere is incapable of using spelling-to-sound mapping rules as Coltheart (1980) has suggested, then the right hemisphere's apparent inability to make rhyme decisions may be due to the hemisphere's inability to map orthographic representations onto phonological representations rather than a general lack of knowledge of the concept of a rhyme (as suggested by Levy, 1974). If this is the case, the right hemisphere ought to be as proficient as the left hemisphere at judging whether spoken words rhyme. Only the left hemisphere, however, should be influenced by the orthographic similarity of the rhyme pairs. Some evidence in support of these conjectures comes from a number of studies examining the phonemic discrimination abilities of the hemispheres. Dennis and Whitaker (1976) found no difference in the phonemic discrimination abilities of three patients with surgically removed right and left hemispheres. Similar results were obtained by Gainotti, Caltagirone, Miceli, and Masullo (1981) and Rankin, Aram, and Horwitz (1981). Morais and Darwin (1974) and Morais (1975) found no ear differences for same judgments to sequences of CV syllables, although there was a right ear advantage for different judgments.

Experiment 1 was conducted in order to examine the possible lateralization of orthographic effects in auditory rhyme monitoring. The prediction, based on the code-integration hypothesis, was that only the left hemisphere should be influenced by the orthographic similarity of the target stimuli. The present study tested this hypothesis using the rhyme monitor task used by Seidenberg and Tanenhaus (1979).

EXPERIMENT 1

Method

Subjects. Twenty Hamilton College students were paid two dollars each for participating in the experiment. All subjects were right-handed and reported having normal hearing. Twelve of the subjects were female and eight were male.

Stimulus materials. Stimuli were constructed in a similar fashion to those reported in Seidenberg and Tanenhaus (1979). All stimuli were monosyllabic rhymes. One-half of all rhymes were orthographically similar (e.g., joke–woke), while the other half were orthographically dissimilar (e.g., dirt–hurt). Uncommon words, homonyms, homophones, homographs, unusual spellings, and predictable rhymes were not used. Word frequency was controlled as nearly as possible by using the Kucera and Francis (1967) norms. For critical trials median frequencies were 14 for cues, 23 for orthographcally similar targets, and 32 for orthographically dissimilar targets. The cues and targets presented on critical trials are given in Appendix A.

There was a total of 72 trials, each containing a rhyme pair. The trials were recorded on a stereo cassette tape by a female speaker. Cue words were recorded on both channels while the targets were taped on a single channel. The targets were equally distributed over both channels, and across the three possible target positions.

Procedure. On each trial, subjects were binaurally presented with an isolated cue word, followed 2 sec later by a monaural list of three semantically unrelated target words recorded at a rate of one per second. On half the trials the target words were presented to the left ear; on the other half they were presented to the right ear. There was a 5-sec pause between trials. Subjects were instructed that their task was to detect as quickly as possible the one target word in the list that rhymed with the cue word. Each subject was given eight practice trials.

Critical trials consisted of the 24 trials in which the target word was in the second position in the three word list. Consistent with Seidenberg and Tanenhaus (1979), the other 48 trials were filler trials: the 24 containing the target word in the first position were not scored due to extreme variability in reaction times, while the 24 containing the target word in the third position were not included due to a large number of anticipatory responses.

The stimuli were recorded on a TEAC 360S cassette tape recorder, and heard by the subjects over Koss-Pro 4AA stereo headphones. The experimenter heard the same stimuli as the subjects over a second set of headphones. On each trial the experimenter turned the gain of a voice key to a set point immediately following the first target word in the list in order to allow the onset of the second word in the list to trigger the voice key and initiate timing on a Lafayette Model 544415 millisecond timer. The timer stopped when the subject pressed a telegraph key indicating detection of a rhyme. The experimenter had approximately 600 msec after the offset of the first word to set the gain of the voice key, which provided her with more than enough time. The experimenter did not have either a list of the stimuli or a condition key in front of her as she was conducting the experiment. She therefore did not know whether the second word—the word triggering the voice relay—was a target word or not, until after the gain was set. Thus the experimenter was blind as to the experimental condition on each trial until after she had set the gain.[1] The experimenter sat behind a large screen which prevented the subject from observing the procedure used to activate the voice relay. The headphones were reversed for half of the subjects in order to control for any possible intensity imbalance between the two channels.

Results and Discussion

Mean latencies for each subject were computed by collapsing across the six exemplars in each of the four conditions and analyzed using a two-way ANOVA with orthographic similarity and ear of presentation as factors. Mean latencies and error rates for each condition are presented in Table 1.

Orthographically similar rhymes were detected 60 msec faster than dissimilar rhymes, $F(1, 19) = 8.54$, $p < .01$, replicating the advantage for orthographically similar rhymes reported by Seidenberg and Tanenhaus (1979) and Donnenwerth-Nolan et al. (1981). Rhyme monitoring latencies were 29 msec faster for rhymes presented to the right ear than for rhymes presented to the left ear, $F(1, 19) = 7.43$, $p < .02$.

[1] For trials on which the first word rhymed with the cue, the experimenter would know that the trial was a filler trial.

Of most interest was a significant interaction between orthographic similarity and ear of presentation, $F(1, 19) = 5.38, p < .05$. This interaction was obtained because there was a 57-msec right ear advantage for orthographically similar rhymes and no difference between ears for orthographically dissimilar rhymes. Planned comparisons revealed that the 89-msec advantage of orthographic similarity for stimuli presented to the right ear was significant, $F(1, 19) = 25.61, p < .01$, whereas the 32-msec advantage of orthographic similarity for stimuli presented to the left ear was nonsignificant, $F(1, 19) = 3.17, p > .05$. The 57-msec advantage for the right ear in responding to orthographically similar rhymes was significant, $F(1, 19) = 10.8, p < .01$, whereas there was no difference between the two ears of presentation in processing orthographically dissimilar rhymes, $F < 1$.

The results are, on the whole, consistent with the hypothesis that visually-based codes and sound-based codes are not integrated in the right hemisphere. Orthographic similarity had an extremely robust effect on responses to rhymes presented to the right ear. The effect was substantially reduced but not completely eliminated for rhymes presented to the left ear.

There are several possible explanations for the interaction between ear of presentation and orthography. One possibility is that the orthographic and phonological codes for words are integrated in the left hemisphere but not in the right. Rhyme judgments based on left hemisphere representations will show an orthography effect, while those based on right hemisphere representations will not. On this account the marginal orthography effect that was obtained with left ear presentation probably occurred because most but not all rhyme decisions were being made using right hemisphere lexical representations. Some decisions could have been made either on the basis of the lexical codes accessed by the left hemisphere or on the basis of a sound-based code which is transferred from the right to the left hemisphere.

A second possibility is that the right hemisphere does not contain lexical representations, but rhyme decisions can be made using a physical

TABLE 1
MEAN RHYME DECISION LATENCIES[a] FOR EXPERIMENT 1

	Orthography type	
	Dissimilar	Similar
Ear		
Left	680 (3.1)[b]	648 (2.5)
Right	680 (2.7)	591 (2.9)

[a] In msec.
[b] Error rates in parentheses.

match strategy. Words that are acoustically similar are judged rhymes while those that are not are judged to be nonrhymes. Such an explanation was proposed by Zaidel (1978), who claimed that the right hemisphere can identify both auditory and visual inputs by their gestalts, or holistic structure, as well as by attending to extralinguistic contexts. Levy (1974) has offered a similar view. However, despite Levy's belief that the right hemisphere can process the holistic nature of speech sounds, she claimed that

> . . . while it can decode meaning from linguistic input and can produce meaningful linguistic output, it could not know that the written word "ache" rhymed with the written word "lake" (page 161).

Levy is thus proposing that rhyme decisions based on an orthographic-to-phonological transformation cannot be made by the right hemisphere, an idea consistent with the hypothesis presented earlier. Levy goes on to claim that although auditory gestalts can be compared by the right hemisphere, the right hemisphere "could not know . . . that the English designation for a cat sounded similar to the English designation for a rat" (page 191).

Although the results of Experiment 1 demonstrated that Levy's proposed inability to perform on all types of rhyming tasks is incorrect, it is still possible that with left ear presentation, most rhyme judgments are made using a physical rather than a lexical strategy.

EXPERIMENT 2

The second experiment was conducted to replicate the results obtained in Experiment 1. Two additional variables were also included. First, the cue and rhyme word were presented either in the same voice or in different voices. The voice manipulation was included to test the hypothesis that right hemisphere rhyme decisions were being made on the basis of a physical match. Presenting the cue and target words in different voices might interefere with physical matching. Therefore, rhyme decisions to cues and targets presented in different voices might be more difficult with left ear presentation than with right ear presentation relative to decisions to cues and targets presented in the same voice. Moreover, if different voice presentation forces rhyme decisions to be made on the basis of a lexical representation, we might expect a larger orthography effect with left ear presentation for stimuli presented in different voices compared to stimuli presented in the same voice. Secondly, we included nonrhyme trials in which the orthographic similarity of the nonrhymes was systematically varied.

Method

Subjects. Fourteen Hamilton College students were paid two dollars each for participating in the experiment. All subjects were right-handed and had self-reported normal hearing. Eight subjects were female and six were male.

Stimulus materials. Stimuli were constructed in a fashion similar to Experiment 3 of Seidenberg and Tanenhaus (1979). A total of 128 pairs of words were presented. One half of these pairs rhymed; within the rhyme pairs, one-half were orthographically similar and the other half orthographically dissimilar. Stimuli are presented in Appendix B.

Two additional manipulations were included: ear of presentation and voice of the speaker. Within each rhyme/orthography combination, one-half of the rhyme pairs were presented to the left ear and the remaining half to the right ear. Finally, within each rhyme/orthography/ear combination, one half of the pairs were spoken in the same voice, either both male or both female, while the other half were spoken in different voices, female–male or male–female.

The design was a 2 × 2 × 2 factorial, with two levels of each of the following factors: voice (same vs. different); orthography (same vs. different), and ear (left vs. right).

Procedure. On each trial, the subject heard a cue word presented to one ear followed approximately 2 sec later by a target word to the same ear. The subject's task was to indicate by pressing the appropriate telegraph key whether the two words rhymed. The hand used to indicate each response (rhyme or nonrhyme) was counterbalanced across subjects. The experimenter, who was blind as to which experimental condition was presented on each trial, adjusted the gain on a voice relay following the cue word in order that the target word would trigger the voice relay. The headphones were reversed on half of the subjects to correct for any intensity imbalance between the two channels.

Results and Discussion

Mean latencies for each subject were computed by collapsing across the eight exemplars in each condition. Overall mean latencies and error rates to the rhymes are presented in Table 2.

Orthographically similar rhymes were detected 37 msec faster than dissimilar rhymes and this difference was significant, $F(1, 13) = 4.80$, $p < .05$. The effects of ear and voice did not reach significance, $F < 1$ and $F(1, 13) = 1.46$, respectively. No interactions reached significance except for the orthography × ear interaction, $F(1, 13) = 11.51$, $p < .001$. Simple main effects tests indicated that the 51 msec effect of orthography was significant for the right ear, $F(1, 13) = 23.24$, $p < .01$, but the 22 msec effect was not significant for the left ear, $F(1, 13) =$

TABLE 2
MEAN RHYME DECISION LATENCIES[a] FOR RHYMING PAIRS IN EXPERIMENT 2

	Same voices		Different voices	
Orthography type:	Dissimilar	Similar	Dissimilar	Similar
Ear				
Left	745 (3.7)[b]	714 (1.9)	745 (3.4)	732 (2.7)
Right	756 (3.1)	695 (2.7)	759 (3.6)	718 (2.9)

[a] In msec.
[b] Error rates in parentheses.

3.20, $p > .05$. The main effect of ear was nonsignificant for both orthograhically similar and dissimilar rhymes, $F(1, 13) = 3.68$, $p > .05$, and $F(1, 13) = 2.18$, $p > .05$, respectively.

The rhyme results replicate the pattern obtained in Experiment 1. Orthographic similarity had a more pronounced effect on rhyme decisions to words presented to the right ear than on rhyme decisions to words presented to the left ear. In addition, there was a right ear advantage only for orthographically similar rhymes. However, the magnitude was small and it did not quite reach significance.

The nonrhyme data are presented in Table 3. There was a significant effect of orthography, $F(1, 13) = 16.68$, $p < .01$, with orthographically similar nonrhymes being responded to more slowly than orthographically dissimilar nonrhymes. However, this effect probably cannot be attributed solely to orthography because orthographic similarity was confounded with phonemic similarity. Orthographically similar nonrhymes were more phonemically similar than orthographically dissimilar nonrhymes. For instance, the coda (final consonant or consonant cluster) was the same for all but three of the orthographically similar nonrhyme pairs (phase–base, tease–lease, and choose–loose), whereas it was different for all but three of the dissimilar nonrhyme pairs. Thus the nonrhyme results are only of marginal interest. There was also an effect of ear with stimuli presented to the left ear being responded to more slowly than stimuli presented to the right ear, $F(1, 13) = 5.93$, $p < .05$. The only interaction to approach significance was the ear by voice interaction, $F(1, 13)$, $= 3.14$, $.05 < p < .10$. This interaction approached significance because nonrhyme stimuli presented to the left ear were responded to more quickly when spoken in the same voice than when spoken in different voices, whereas voice similarity did not affect nonrhyme decisions to stimuli presented to the right ear.

The results of this experiment replicate the basic pattern obtained in Experiment 1. Orthograhic similarity had a more pronounced effect on rhyme decisions to words presented to the right ear than to words presented

TABLE 3
MEAN RHYME DECISION LATENCIES[a] FOR NONRHYMING PAIRS IN EXPERIMENT 2

	Same voices		Different voices	
Orthography type:	Dissimilar	Similar	Dissimilar	Similar
Ear				
Left	788 (2.6)[b]	839 (4.0)	800 (3.3)	857 (3.9)
Right	786 (2.8)	828 (3.9)	781 (3.7)	822 (5.0)

[a] In msec.
[b] Error rates in parentheses.

to the left ear. As in Experiment 1, there was a right ear advantage only for orthographically similar rhymes, but this effect was small and did not quite reach significance. However, a right ear advantage was found for the nonrhymes and the lack of an overall ear effect for the rhymes needs to be interpreted with some caution given the difficulty of obtaining ear effects with monaural tasks.

On balance the results do not support the hypothesis that rhyme decisions with left ear presentation were being made on the basis of a superficial physical match. Both rhyme and nonrhyme judgments were no more difficult when words were spoken in the same voice than when words were spoken in different voices. Moreover, similarity of voice did not interact with ear of presentation for the rhymes, although this interaction did approach significance for the nonrhymes.

It is possible that the voice manipulation was ineffective, and that a physical match based on a gestalt or image of the two stimuli could still be made. Although care was taken in selecting two voices which were as different as possible, it may have been the case that sufficient physical invariants (intensity, aspiration, and other parameters) were present to allow for physical matches. Some support for this possibility comes from Caramazza et al. (1983) who reported a case study of an aphasic patient who was totally incapable of discriminating between synthetic speech sounds, while demonstrating virtually perfect discrimination of natural speech. Caramazza et al. interpreted this as indicating that the subject had the ability to process auditory but not phonetic information. Thus, perhaps the manipulation used in the present experiment also allowed sufficient auditory information to be processed so that a physical match strategy was still viable. It is also possible that the right hemisphere was making rhyme judgments based on prelexical phonetic representations which would be unaffected by our voice manipulation.

The results of Experiments 1 and 2 clearly support the hypothesis that lexical codes exist in both hemispheres, but are integrated only in the left hemisphere. This hypothesis suggests that the bilateral representation of the lexicon should lead to equal performance by the two hemispheres on tasks which do not require spelling-to-sound or sound-to-spelling mapping. Experiment 3 used the lexical decision task to examine hemispheric differences in semantic processing of spoken words.

EXPERIMENT 3

Subjects. Twenty Hamilton College students were each paid two dollars for participating in the experiment. Ten subjects were female and ten were male. All subjects were right-handed and all had self-reported normal hearing.

Stimulus materials. The stimuli were taken from the set reported by Meyer, Schvaneveldt, and Ruddy (1975). A total of 80 pairs of letter strings were presented. Of these, 40 consisted of word–word pairs and 40 had one or both letter strings which were nonwords. Nonwords were created by changing one phoneme of a word. Among the word–word ("yes") pairs, one half consisted of semantically related pairs and the other half was unrelated. Similarly, there were three types of "no" trials: nonword–word (NW), word–nonword (WN), and nonword–nonword (NN) pairs, with 13, 14, and 13 pairs of each type, respectively.

As in Experiments 1 and 2, an ear of presentation manipulation was included. One half of all pairs were presented to the left ear and the remaining half to the right ear.

Procedure. On each trial, the subject heard a letter string presented to one ear, followed approximately 2 sec later by the second letter string to the same ear. The subject's task was to indicate by pressing the appropriate telegraph key whether both letter strings were legitimate words. For those trials where a "no" response was required, the procedure used to measure reaction time differed from the procedure employed in Experiments 1 and 2. Since on nonword–nonword and nonword–word trials the subject responded following the first stimulus, reaction times on these trials were recorded from the onset of the first stimulus. On word–nonword (and all "yes" trials) reaction times were recorded from the onset of the second stimulus. The hand used to indicate each response (word vs. nonword) was counterbalanced across subjects. As in the previous experiments, the headphones were reversed on half of the subjects to correct for any possible intensity imbalance between the two channels.

Results and Discussion

Mean latencies for each subject for the "yes" trials were computed by collapsing across the 10 exemplars in each of the four conditions and analyzed using a two-way ANOVA with semantic relatedness and ear of presentation as factors. Overall mean latencies and error rates are presented in Tables 4 and 5. Separate ANOVAs were performed on the "yes" and "no" responses.

The "yes" data replicated the typical effect of semantic relatedness. Related word pairs were responded to 106 msec faster than unrelated word pairs and this difference was significant, $F(1, 18) = 82.83$, $p < .0001$. The effect of ear of presentation did not reach significance ($F < 1$), nor did the relatedness × ear interaction ($F < 1$).

The analysis of the "no" data indicated that there was a significant effect of type of pair. The three types of letter string pairs produced significantly different response latencies, $F(2, 36) = 8.66$, $p < .001$. Paired comparisons indicated that the WN pairs were responded to significantly faster than NW and NN pairs, which did not differ. The ANOVA

TABLE 4
MEAN LEXICAL DECISION LATENCIES FOR "YES" RESPONSES IN EXPERIMENT 3[a]

	Semantic relationship	
	Related	Unrelated
Ear		
Left	684 (1.7)[b]	788 (2.3)
Right	674 (1.7)	783 (1.3)

[a] In msec.
[b] Error rates in parentheses.

TABLE 5
MEAN LEXICAL DECISION LATENCIES FOR "NO" RESPONSES IN EXPERIMENT 3[a]

	Type of pair		
	Word–nonword	Nonword–word	Nonword–nonword
Ear			
Left	940 (6.7)[b]	1137 (6.7)	1095 (1.4)
Right	981 (7.1)	1084 (10.0)	1142 (2.5)

[a] In msec.
[b] Error rates in parentheses.

also showed no effect for ear of presentation ($F < 1$) and no ear × pair type interaction, $F(2, 36) = 1.18$, $p > .05$.

These results replicate previous research and support the hypothesis stated earlier that the two hemispheres both contain lexical codes. The main effect type of letter string pair for the "no" data simply appears to indicate that subjects were faster when responding to a nonword in the second position of a pair, and does not seem to be of any further theoretical importance for this study.

The lack of a significant right ear advantage is interesting given that a right visual field advantage typically obtains in lexical decisions or naming tasks with visual presentation (e.g., Hines, 1975; Klein, Moscovitch, & Vigna, 1976). The absence of a right ear advantage in our experiment needs to be interpreted with some caution given the difficulty of obtaining such effects with monaural presentation. However, Henry (1979) reports that during the period from 1967 to 1978, 74 studies using monaural stimulation did elicit an ear advantage, in the form of both main effects and interactions. Although ear differences may be difficult to obtain with monaural presentation, there is a large literature which supports their existence. Further research is clearly needed in order to determine whether there is a reliable interaction between laterality effects and modality of presentation.

GENERAL DISCUSSION

The present experiments explored the lateralization of orthographic effects in rhyme monitoring using a rhyme monitoring task. The results replicated Seidenberg and Tanenhaus (1979) and Donnenwerth-Nolan et al. (1981) in demontrating that orthographically similar rhymes are detected more rapidly than orthographically dissimilar rhymes when all stimuli are presented auditorily. The results further demonstrated that orthographic effects on rhyme monitoring are more robust when stimuli are presented to the right ear than when they are presented to the left ear. They also showed that a right ear advantage for rhyme detection holds only for orthographically similar rhymes.

Our studies clearly support the code integration hypothesis proposed by Coltheart (1980). The fact that orthographic effects in auditory word recognition appear to be lateralized to the left hemisphere suggests that the inability of the right hemisphere to perform a phonological analysis on printed words may not be due to a specific inability to use phonological codes but rather due to a general inability to integrate phonological and orthographic codes, a process that is essential for the effect of orthography to be observed. Thus, the right hemisphere is as fast as the left hemisphere in deciding that two orthographically dissimilar words rhyme, since the dissimilar orthography will not result in a facilitative code integration process. When the two words are orthographically similar, however, the left hemisphere has an advantage: A facilitative effect of orthography is observed because the left hemisphere has integrated the phonological and orthographic codes. The code integration hypothesis is able to reconcile many of the seemingly discrepant results concerning the rhyming capabilities of the right hemisphere. When the stimulus presentation modality is visual, the right hemisphere performs very poorly (if at all) on rhyming tasks. However, with auditory presentation, the right hemisphere demonstrates an ability to make rhyme decisions as well as the left hemisphere. The results are explained by taking into consideration both the task demands and the code integration abilities of the two hemispheres.

The relationship between the access of sound-based codes in visual word recognition and spelling-based codes in auditory word recognition remains an issue for future investigation. Several possibilities remain viable. One possibility is that code integration results from the child learning spelling–sound mapping rules during beginning reading. Spelling effects in auditory word recognition are the result of spelling–sound mappings becoming automatized. A second possibility is that there are sound–spelling rules which are similar to spelling–sound rules. These rules may be learned by the child in the course of learning to spell. Finally, integrated codes may arise in the absence of spelling–sound or sound–spelling mapping rules because the child learns to integrate spelling and sound information as a learning heuristic (Ehri, 1980).

The results do not shed any light on why the hemispheres should differ in their ability to integrate phonological and orthographic codes. One likely possibility is that code integration develops as a function of extensive practice in mapping between codes in production tasks (e.g., reading aloud) which are controlled predominantly by the left hemisphere.

There is a second aspect of our results for which the interpretation is more clouded. In both Experiments 1 and 2 we failed to find a right ear advantage for detecting orthographically dissimilar rhymes. One possibility is that both the right and the left hemispheres can make rhyme judgments; however, they make the judgments based on different codes. The left hemisphere contains an integrated lexical representation of a word. This representation includes a specification of its semantic, phonological, and orthographic codes. When a word is recognized by the left hemisphere all of these codes become available. Similarity on any of these codes will facilitate same judgments, regardless of the nature of the dimension. The right hemisphere might also be able to make rhyme judgments based on a different type of representation. The right hemisphere might make rhyme judgments based on overall similarity. However, the results of Experiment 2 indicate that these judgments are not based on anything as shallow as a purely physical match. If this were the case, there should have been an interaction between same or different voice and ear of presentation in Experiment 2. An alternative is that the right hemisphere sends a code to the left hemisphere. This code might be a sound-based code or it might be a meaning-based code. The left hemisphere can then use this code to make a rhyme decision if it is a sound-based code or first retrieve a sound-based code and then make a rhyme decision if the code is meaning-based. Such a transmission of code information from the right hemisphere to the left hemisphere would take time; the small right ear reaction time advantage in Experiment 1 and the absence of any ear advantage in Experiment 2 would appear to argue against such an explanation.

The interpretation that we prefer is that only the left hemisphere contains integrated lexical codes. The two hemispheres of the brain are both capable of making rhyme decisions, but they do so based on different processes. The left hemisphere is apparently able to integrate lexical codes, thus benefiting from orthographic similarity in an auditory task, whereas the right hemisphere, which possesses these codes, is incapable of such integration.

APPENDIX A

List of Stimuli Used in Experiment 1

Orthographically similar cues and targets	Orthographically dissimilar cues and targets
joke–woke	gum–dumb
glue–clue	dirt–hurt
tree–fee	tune–noon
fad–glad	coal–stole
pie–tie	kite–flight
blade–grade	ghost–coast
blur–slur	flame–claim
head–dead	pope–soap
bead–plead	lore–floor
tease–ease	vote–boat
beak–freak	dance–pants
learn–yearn	fool–cruel

APPENDIX B

List of Stimuli Used in Experiment 2

Rhyming		Nonrhyming	
Orthographically Similar	Orthographically Dissimilar	Orthographically Similar	Orthographically Dissimilar
Same voices			
call–hall	bead–deed	tough–cough	bend–howl
tower–power	raise–maze	wart–part	brain–root
howl–growl	tooth–youth	wars–bars	foe–short
tone–bone	leaf–chief	hose–lose	beer–wear
row–low	keys–please	leaf–deaf	cake–row
blood–flood	moan–blown	bomb–tomb	blood–lose
head–dead	heart–tart	phase–base	much–couch
fear–near	mutt–what	gown–flown	deed–fed
lord–cord	grown–tone	mood–good	most–lamb
boot–shoot	two–brew	hoot–foot	hard–bad
hole–mole	door–bore	fear–wear	dish–cool
tease–please	touch–much	done–tone	stone–host
zoom–broom	low–go	cost–host	tooth–cost
blown–flown	towel–growl	call–shall	broom–fear
Different voices			
chief–brief	rude–mood	mood–good	ground–room
host–post	root–fruit	mouth–youth	wall–foe
deed–feed	wars–doors	doll–toll	milk–hoot
hose–prose	toll–mole	couch–touch	most–thank
pool–cool	hoe–slow	tease–lease	goose–map
goose–noose	rule–pool	frost–ghost	dream–flow
hard–yard	ward–lord	word–lord	foot–rust
boot–hoot	ghost–toast	choose–loose	power–aim
post–most	touch–much	yard–ward	glad–ward
rut–nut	hose–doze	hood–blood	less–rock
ghost–most	yard–guard	blower–tower	row–pool
mood–food	crawl–call	cash–wash	well–food
woe–foe	face–case	match–watch	lump–youth
bluff–huff	grow–woe	mow–how	phase–nut

APPENDIX C

List of Stimuli Used in Experiment 3

Word–word pairs	
Semantically related pairs	Semantically unrelated pairs
sick–ill	silent–pail
silent–quiet	bacon–afraid
plate–dish	dish–cat
glad–happy	butler–scared

Word–word pairs	
Semantically related pairs	Semantically unrelated pairs
bucket–pail	cake–quiet
cake–pie	ill–kitten
butler–maid	plate–sick
bacon–eggs	eggs–happy
afraid–scared	glad–maid
kitten–cat	bucket–pie
lunch–dinner	lunch–scream
lion–tiger	carpet–bee
cup–glass	pillow–honey
yell–scream	knife–tiger
needle–thread	fork–rug
honey–bee	yell–butter
knife–fork	sheets–dinner
bread–butter	thread–lion
carpet–rug	glass–needle
pillow–sheets	bread–cup

	Nonword pairs	
Nonword–nonword pairs	Word–nonword pairs	Nonword–word pairs
gling–sloat	ship–blop	bope–lock
zark–dirf	glow–bign	lund–park
lork–jate	juice–tuddle	dorn–wash
mung–joad	pants–glip	keed–wood
biff–fote	trip–lant	nong–tail
garm–fank	lazy–yeak	slen–lion
pring–glit	chair–nage	cath–test
litch–bance	burn–galt	tope–film
tush–haper	stop–tude	nouch–rope
jass–lext	wheel–kail	nink–nest
girt–nard	jump–pask	hake–table
dalt–polt	tire–zild	nush–queen
lorse–vack	dance–mord	mulf-fire
	list-voke	

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