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Phonological Recoding and Use of Spelling-Sound Rules in Reading of Sentences

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Phonological recoding in reading may be accomplished by use of one or both of two different mechanisms—spelling-sound rules and word-specific associations. The three experiments reported focus on phonological recoding in fluent reading of meaningful sentences, and ask whether spelling-sound rules play a role in this process. The results show that effects attributed to spelling-sound rule use—effects previously found in lexical decision tasks with single words—emerge also in sentence-reading tasks. These effects include inhibition on words with similar spellings and different pronunciations and exception word/regular word differences. It is concluded that phonological recoding and spelling-sound rule use continue to be important even for fluent readers.

Most of the research on phonological recoding in reading has centered on the recognition of isolated words. This research reveals that phonological recoding can and often does play a role in lexical access, or the extraction of information about meaning. However, phonological recoding is not obligatory. To capture this flexibility, investigators have proposed a family of dual access models by which phonologically mediated and nonphonologically mediated lexical access proceed in parallel. (For a review, see McCusker, Hillinger, & Bias, 1981.)

Granted that phonological recoding is one method of lexical access, we may ask how the phonological representations of written words are derived. We may distinguish between two possible (classes of) mechanisms—one that takes advantage of such general and productive relations between spellings and sounds as exist, and one that relies on rote associations between printed words and their pronunciations. We shall refer to the first mechanism as involving *spelling-sound rules* and to the second as involving *word-specific associations*. The critical feature of the spelling-sound rule mechanism is that it allows one to derive the pronunciations of unfamiliar words. Readers can do this in several ways, including small-unit rules (e.g., B → "b", A → "a", T → "t"), large-unit rules (e.g., AT → "at"), or analogies (see Baron, 1979, for discussion). Whichever process is used, the reader benefits from the spelling-sound relations that exist in English. Word-specific associations, in contrast, do not take advantage of predictable spelling-sound relations.

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Perhaps the best evidence for the existence of these two mechanisms for derivation of phonological representations is that their relative strengths may vary across individuals. Among normal children, for instance, one can distinguish "Phoenician" readers, who are strong at the first mechanism and weak at the second, and "Chinese" readers, who are weak at the first mechanism and strong at the second (Baron, 1979). A parallel distinction has been made among adults (Baron & Strawson, 1976; Baron, Treiman, Freyd, & Kellman, 1980). The dissociation between the two mechanisms is even clearer in cases of developmental and acquired dyslexia. Some children with severe reading disability appear to be Phoenicians, able to decode written words via spelling-sound rules but poor at memorizing specific associations. Others (most, in fact) are Chinese-style readers, able to read a limited number of words on sight but unable to decode unfamiliar words (Boder, 1973). Among brain-injured adults as well, distinct Phoenician and Chinese patterns have been described (see Luria, 1960; Saffran & Marin, 1977).

Relatively little is known about the use of spelling-sound rules by fluent adult readers. Although fluent readers *can* use rules to decode novel words, it is possible that they bypass these rules when reading familiar words or when reading silently. Even if they continue to use phonological codes in these cases, they may derive these codes by word-specific associations rather than by spelling-sound rules. A study by Baron (1977) and Brooks (1977), however, suggests that adults continue to use spelling-sound rules with familiar items, at least when reading aloud. These investigators compared subjects' ability to pronounce words written in an artificial alphabet under two conditions. In the first condition there were correspondences between the artificial letters and English phonemes; in the second condition there were no such correspondences. Thus, in the first condition subjects could use spelling-sound rules and/or word-specific associations. In the second condition they could use only word-specific associations. After extensive practice, subjects were able to pronounce the items that embodied spelling-sound rules more rapidly than the items that did not. That is, spelling-sound rules continued to aid performance.

Other studies suggest that adult readers use spelling-sound rules in the processing of real English words. Several investigators compared regular words, such as HINT and ROSE, and exception words, such as PINT and LOSE (Baron & Strawson, 1976; Gough & Cosky, 1977; Stanovich & Bauer, 1978). They reported that pronunciation latencies are longer for exception words than for regular words. In addition, Stanovich and Bauer (1978) and Barron (1980) found that exception words lead to longer response times in lexical decision tasks than regular words (at least for good readers). These results suggest that phonological codes, derived in part by use of spelling-sound rules, play a role in recognition and pronunciation of isolated words. Were only word-specific associations involved, one would expect no difference in performance between exception words and regular words.[1]

Another study relevant to the question of spelling-sound rule use in the processing of real words was carried out by Meyer, Schvaneveldt, and Ruddy (1974). These investigators presented subjects with pairs of letter strings. The subjects' task was to decide whether both members of the pair were words. The results showed that pairs

[1] Glushko (1981) has recently criticized studies of this kind, pointing out that both regular and exception words may be pronounced, in part, by analogy with known words. In our formulation, however, use of analogies can be one way of taking advantage of spelling-sound relations (Baron, 1977, p. 181; Baron, 1979). Use of analogies and use of component correspondences both require analysis of printed and spoken words into parts. The difference is in whether the analysis is done at the time of learning or at the time a novel word is read.

such as NASTY–HASTY, in which the words are spelled similarly but pronounced differently, yielded slower response times and more errors than control pairs. Pairs such as NEVER–SEVER, which are spelled similarly and pronounced similarly, were somewhat easier to judge than control pairs, although not significantly so. Shulman, Hornak, and Sanders (1978) later replicated these findings, at least in the situation in which words must be discriminated from orthographically and phonologically legal nonwords. These results, by showing that the phonological relation between the words in a pair influences lexical decision, provide clear evidence for phonological recoding in this task. Furthermore, the difficulty of pairs of words with similar spellings and different pronunciations is consistent with the view that the phonological recoding takes place in part via spelling-sound rules. According to the model proposed by Meyer et al. (1974), a subject uses a particular rule to encode NASTY. The subject then tends to apply the same rule to HASTY, inhibiting performance on this word. An alternative interpretation, however, is that the effect is due not to the use of rules but to the use of specific associations between printed words and sounds. When similar-appearing stimuli—the printed words NASTY and HASTY, for example—are associated with dissimilar sounds, interference could result. (Such a similarity effect could also account for the results of Baron (1977) and Brooks (1977).)

The studies discussed so far involved single words or semantically unrelated pairs of words, and the results cannot automatically be generalized to reading tasks involving meaningful, connected materials. Other studies, however, suggest that (hearing) readers do recode phonologically during silent reading of complete sentences (e.g., Corcoran, 1966; Kleiman, 1975; Treiman & Hirsh-Pasek, 1983). Indeed, some investigators have hypothesized that readers rely on phonological recoding to a greater extent when reading sentences than when reading individual words due to the greater memory demands posed by sentence comprehension (Baron, 1977; Kleiman, 1975; Tzeng, Hung, & Wang, 1977).

Although the studies cited above suggest that phonological recoding occurs during silent reading of sentences, they do not indicate how the phonological codes are derived. As with isolated words, readers may use spelling-sound rules, word-specific associations, or some combination of the two. One study attempted to address this issue indirectly by comparing the extent of phonological recoding in the reading of English and Chinese sentences (Treiman, Baron, & Luk, 1981). If spelling-sound rules contribute to phonological recoding, one would expect recoding to be used to a greater degree by readers of English than by readers of Chinese, since English offers more spelling-sound relations. The results of Treiman et al. (1981) did show a greater use of phonological recoding by those reading in English. It was therefore suggested that phonological recoding in the reading of English sentences takes place, in part, via spelling-sound rules. That word-specific associations are also used is suggested by the finding that some phonological recoding occurs even among readers of Chinese (Tzeng et al., 1977).

The present experiments focus on the reading of sentences. They show that previous demonstrations of phonological recoding and spelling-sound rule use in reading of isolated words can be extended to reading of words in sentences. Experiment 1 shows that the confusion induced by words with similar spellings and different pronunciations (e.g., Meyer et al., 1974) occurs when the words are embedded in meaningful sentences. Experiment 2 demonstrates that the effect of spelling-sound rule regularity (e.g., Baron & Strawson, 1976) is found in oral reading of sentences. Experiment 3 shows that the same effect is found, at least weakly, even in silent reading of sentences. Together, the

TABLE 1
EXAMPLES OF STIMULI USED IN EXPERIMENT 1

Similar spelling/different pronunciation critical pairs	
Type 1	Type 2
HE MADE A NASTY HASTY REMARK/PROFUSELY	HE MADE A MEAN RASH REMARK/PROFUSELY
BEFORE I CHEATED I SWEATED REMARK/PROFUSELY	BEFORE I LIED I PERSPIRED REMARK/PROFUSELY
Type 3	Type 4
HE MADE A MEAN HASTY REMARK/PROFUSELY	HE MADE A NASTY RASH REMARK/PROFUSELY
BEFORE I LIED I SWEATED REMARK/PROFUSELY	BEFORE I CHEATED I PERSPIRED REMARK/PROFUSELY
Similar spelling/similar pronunciation critical pairs	
Type 1	Type 2
I WILL NEVER SEVER OUR RELATIONSHIP/YOU	I WILL NOT DESTROY OUR RELATIONSHIP/YOU
BRING STRING WITH RELATIONSHIP/YOU	CARRY ROPE WITH RELATIONSHIP/YOU
Type 3	Type 4
I WILL NOT SEVER OUR RELATIONSHIP/YOU	I WILL NEVER DESTROY OUR RELATIONSHIP/YOU
CARRY STRING WITH RELATIONSHIP/YOU	BRING ROPE WITH RELATIONSHIP/YOU

results of these experiments strengthen the argument for use of phonological recoding, through use of spelling-sound rules, in reading of text.

EXPERIMENT 1

Experiment 1 asked whether the results found by Meyer et al. (1974) and Shulman et al. (1978) in a word-pair lexical decision task generalize to a sentence-reading task. We embedded pairs of similar spelling/different pronunciation words such as NASTY and HASTY in sentence fragments such as HE MADE A NASTY HASTY. As a measure of reading ease, subjects engaged in a forced-choice sentence completion task. For example, the fragment HE MADE A NASTY HASTY was presented with a choice of two completions, REMARK or PROFUSELY. Subjects were to choose the word that made a complete and meaningful sentence. Table 1 shows that this sentence completion item exemplifies a Type 1 trial based on a similar spelling/different pronunciation pair of critical words. The Type 2 trial generated from this pair replaces the two critical words, NASTY and HASTY, with their rough synonyms, MEAN and RASH. In the Type 3 trial only the first member of the pair is replaced with its synonym, while in the Type 4 trial only the second member of the pair is replaced. If performance were determined only by the particular words used, not by which word is combined with which, the performance difference between trial types 1 and 3 would equal that between 4 and 2. For example, if the word NASTY were more difficult to read than the word MEAN, subjects would perform more poorly on trial type 1 than trial type 3, and more poorly on trial type 4 than trial type 2. If $p(i)$ is performance on trial type i (where $i = 1, 2, 3$, or 4), we would expect that $p(1) - p(3) = p(4) - p(2)$, or $p(1) + p(2) = p(3) + p(4)$. On the other hand, if a confusion effect is present in the sentence completion task as it is in the lexical decision task, performance on trial type 1 would be poorer than we would otherwise expect. In this case, performance on trial types 1 and 2 would be poorer than performance on trial types 3 and 4, or $p(1) + p(2) < p(3) + p(4)$. Note that the same words occur in trial types 1 and 2 as in trial types 3 and 4; only their arrangement is different. Thus, the comparison between trial types 1 and 2 and trial types 3 and 4 controls for differences among words due to frequency and other factors.

Other critical pairs, such as NEVER–SEVER and BRING–STRING, contained words with similar spellings and similar pronunciations. As shown in Table 1, each such critical pair also generated four sentence completion trials. If the results on these trials parallel those found in lexical decision, we expect no decrement in performance (and even some facilitation) on trial types 1 and 2 relative to trial types 3 and 4.

Finally, the critical prediction made by the phonological recoding hypothesis is that the decrement on trial types 1 and 2 relative to trial types 3 and 4 will be greater for similar spelling/different pronunciation critical pairs than for similar spelling/similar pronunciation critical pairs. Such a result would indicate that the phonological relation between pairs of visually similar words that are near to each other in sentences influences subjects' performance. In this case, we would have clear evidence that subjects recode the printed words into their phonological forms while reading silently.

Method

Stimuli. The stimuli were based on 16 critical pairs of words, 8 with similar spellings and different pronunciations and 8 with similar spellings and similar pronunciations. Four sentence completion trials were generated from each pair. Type 1 trials contained both critical words, Type 2 trials contained both synonyms, Type 3 trials contained the first synonym and the second critical word, and Type 4 trials contained the first critical word and the second synonym. The sentence fragments were between three and six words long. All four trial types for a given critical pair were associated with the same two sentence completion choices. Answer choices were shared between two critical pairs such that each answer choice was correct half the time it appeared and incorrect half the time. The experiment included, in addition to the 64 experimental trials just described, an equal number of filler trials. There were also 16 practice trials. The experimental stimuli are shown in the Appendix.

Procedure. Stimuli were presented on a Commodore PET computer screen. Subjects were instructed to read each sentence fragment silently and to choose one of the two words presented below the incomplete sentence as the best ending for that sentence. If they chose the alternative presented on the left side of the slash they were to push the left-hand response key; if they chose the right alternative they were to push the right-hand response key. The instructions stressed that accuracy was important. Each trial began with a 2-second blank screen. Then the incomplete sentence appeared. The two answer choices were printed four lines below the sentence with a slash between them. The subject's response initiated the blank screen interval for the next trial. The practice trials were presented first, followed by the test trials. The order of presentation of the test trials was randomized for each subject.

Subjects. The subjects were 16 undergraduates who were paid for their participation.

Results and Discussion

Since the error rate was very low in this study (less than 2%), and since errors did not differ as a function of condition, response times were the major focus of analysis. For sentence completion trials based on critical pairs with similar spellings and different pronunciations, trial types 1 and 2 had a mean response time for correct responses of 1.83 seconds, standard deviation

= .29. Trial types 3 and 4 had a mean response time of 1.64 seconds, SD = .26. This difference was statistically significant, both when tested across subjects, $t(15) = 5.07$; $p < .0005$, one tailed, and when tested across items, $t(7) = 3.33$, $p < .01$, one tailed. The mean response times for the individual sentence types were 1.88 seconds for Type 1 sentences, 1.77 seconds for Type 2 sentences, 1.69 seconds for Type 3 sentences, and 1.59 seconds for Type 4 sentences. These individual means must be interpreted with caution, since they are affected by differences among words due to frequency and other factors. Nevertheless, it appears that Type 1 sentences, which contained both critical words, did produce the longest response times.

For sentence completion trials based on critical pairs with similar spellings and similar pronunciations, correct responses to trial types 1 and 2 took 1.54 seconds, SD = .23, while those to trial types 3 and 4 took 1.46 seconds, SD = .21. This difference was significant when tested across subjects, $t(15) = 2.50$, $p < .05$, two tailed, but did not reach significance when tested across items, $t(7) = 1.48$. The individual means were 1.59 seconds for Type 1, 1.49 seconds for Type 2, 1.49 seconds for Type 3, and 1.42 seconds for Type 4.

Importantly, the difference between trial types 1 and 2 and trial types 3 and 4 was significantly greater for similar spelling/different pronunciation critical pairs than for similar spelling/similar pronunciation critical pairs, across subjects $t(15) = 3.29$, $p < .005$, one tailed; across items $t(14) = 2.07$, $p < .05$, one tailed. That is, the phonological relation between the members of a critical pair influenced performance. Readers were significantly more impaired by similar spelling/different pronunciation pairs than by similar spelling/similar pronunciation pairs. This finding extends one found earlier in the lexical decision task (Meyer et al., 1974; Shulman et al., 1978) to a task involving meaningful sentences. The finding provides clear evidence for phonological recoding in the sentence completion task and further suggests, if we follow the reasoning of Meyer et al. (1974), that spelling-sound rules are involved in the recoding process. According to this interpretation, subjects perform particularly poorly on sentences containing nearby words with similar spellings and different pronunciations because they tend to apply the same spelling-sound correspondences to both words. As discussed above, however, the confusion effect could also stem from use of specific associations between printed words and phonological forms.

In one respect the present results appear to differ from those found in lexical decision. Meyer et al. (1974) and Shulman et al. (1978) found some facilitation on similar spelling/similar pronunciation pairs relative to controls. This facilitation was not statistically significant in the former study but was significant in the latter. In contrast, we found a decrement on sentence completion trials containing similar spelling/similar pronunciation word pairs (at least when tested across subjects). While this decrement was, importantly, smaller than that found with similar spelling/different pronunciation pairs, it is interesting to consider its origin. We suggest that in the present task, in which subjects must remember and integrate the words in the sentence fragment before making their sentence completion choice, working memory plays a larger role than it does in the lexical decision task. As is well known, printed letters or words whose phonological representations are similar cause difficulty in immediate serial recall (Baddeley, 1966; Conrad & Hull, 1964; Wickelgren, 1965). Indeed, previous studies with sentence materials have found, like this one, that readers have difficulty with sentences containing many words with similar pronunciations and similar spellings (Baddeley & Hitch, 1974). Thus, while similar spelling/similar pronunciation word pairs may cause facilitation in lexical decision tasks, they seem to cause difficulty in sentence comprehension due to the memory demands involved.

Despite this minor discrepancy between

TABLE 2
EXAMPLES OF SENTENCES USED IN EXPERIMENTS 2 AND 3 TO ASSESS USE OF SPELLING-SOUND RULES

Exception word sentence, Correct	GEORGE WASHINGTON WAS A GREAT LEADER.
Exception word sentence, Incorrect	THE HOSTESS CAME DOWN TO GREAT HER GUESTS.
Regular word sentence, Correct	THE HOSTESS CAME DOWN TO GREET HER GUESTS.
Regular word sentence, Incorrect	GEORGE WASHINGTON WAS A GREET LEADER.
Exception word sentence, Correct	HE WORE A PLAID SHIRT.
Exception word sentence, Incorrect	THE CHILDREN PLAID OUTDOORS.
Regular word sentence, Correct	THE CHILDREN PLAYED OUTDOORS.
Regular word sentence, Incorrect	HE WORE A PLAYED SHIRT.

the present results and the earlier ones, the major finding of Experiment 1 is clear. The phonological relation between nearby words in a sentence affects subjects' performance. Performance is particularly poor when adjacent words have similar spellings but follow different spelling-sound rules. These results indicate that subjects use phonological codes in the sentence-reading task.

Experiments 2 and 3 were designed to further study the way in which these phonological codes are derived. They did so by asking whether the spelling-sound rule regularity effect, previously found with isolated words, occurs also with words in sentences.

EXPERIMENT 2

Experiment 2 asked whether subjects use spelling-sound rules when reading words in sentences *aloud*. The method involved a comparison of exception words and regular words. As described above, previous studies have shown that exception words take longer to name than regular words and that they lead to longer response times in lexical decision tasks (Baron & Strawson, 1976; Barron, 1980; Gough & Cosky, 1977; Stanovich & Bauer, 1978). These results have been interpreted to mean that subjects use spelling-sound rules to code written words phonologically, so that words that follow uncommon or unproductive rules are at a disadvantage. Experiments 2 and 3 asked whether the same effects emerge when exception words and regular words are embedded in sentences. Experiment 2 studied oral reading while Experiment 3 involved silent reading. In addition to the use of sentence materials, these experiments also differed from the previous studies in the nature of the exception word/regular word pairs. They used pairs such as GREAT–GREET and PLAID–PLAYED. These pairs have the property that if the exception word were pronounced according to the major spelling-sound correspondences of English (as defined by Venezky, 1970) it would sound like the regular word. The regular word, in contrast, cannot legally be pronounced like the exception word. These pairs allow us to ask whether exception words are misread as regular words more than the reverse. We hoped to amplify any detrimental effect of spelling-sound rule irregularity by using the sentence context to potentiate such misreading. Of course, the sentence context would also potentiate the reverse misreading, should it occur.

From each exception word/regular word pair, four sentences were generated. Examples are shown in Table 2. Two of the sentences contained the exception word. One of these was correct (i.e., grammatical and sensible) and one was incorrect. Two other sentences replaced the exception word with the regular word. Again, one of these sentences was correct and one incorrect. If subjects use spelling-sound rules they should have more difficulty with the sentences containing exception words than with the sentences containing regular words. By comparing performance on both types of exception word sentences (i.e., correct and incorrect) to both types of regular word sentences we control for sentence frame and for sentence correctness.

Method

Stimuli. Twenty-four word pairs of the kind described above were tested for suitability in a pilot experiment. In this experiment, the words were presented in scrambled order to 13 undergraduates. The students were asked whether they were familiar with each word. If so, they were asked how the word was pronounced and whether it could legally be pronounced in another way. The word PRETTY was given as an example of a word that could be pronounced differently according to the spelling-sound rules of English. The subjects were told that some words would have no alternate pronunciations, while others would. For a word pair to be included in the experiment, the regular word pronunciation had to be the most frequently given alternate pronunciation for the exception word. This pronunciation had to be given by at least half the subjects who were familiar with both words in the pair. (For several pairs, such as SLEIGHT–SLATE, some subjects were not familiar with one of the words.) Of the 24 pairs, 18 satisified these criteria. For each of these pairs, a majority of the subjects who knew both words (an average of 73%) gave the regular word as a possible pronunciation for the exception word. Relatively few subjects (an average of 15%) gave the exception word as a possible pronunciation for the regular word.[2] The exception words had a median frequency, according to the Kučera and Francis (1967) norms, of 191, the regular words of 33.5. These values did not differ significantly by a Wilcoxon test.

For each exception word/regular word pair, two sentence frames were constructed. The exception word made an acceptable English sentence when placed in the first frame and an unacceptable sentence when placed in the second. The regular word made an unacceptable sentence when placed in the first frame and an acceptable sentence when placed in the second. The sentences ranged in length from 5 to 11 words, and are shown in the Appendix.

The sentences were typed in upper and lower case letters on 5 × 8-in. cards, two sentences per card. For this purpose the word pairs were grouped into sets of two; each card contained a sentence generated from each member of the set. The two sentences on a card contained the same type of key word—exception or regular—but could differ in correctness. The test cards were arranged in two different pseudorandom sequences such that half of the exception word cards preceded the corresponding regular word cards and half of the exception word cards followed the corresponding regular word cards. In addition, there were eight practice cards that contained sentences similar to the test sentences.

Procedure. The subjects were asked to read aloud the two sentences on each card. They were told to read as quickly as possible and without worrying about mistakes. Subjects were told in advance that some of the sentences would not make sense. The subjects read the eight practice cards and then went through the test cards two times.

[2] For *none* of the word pairs pretested did more subjects give the exception word as a possible pronunciation for the regular word than the reverse. Our goal, in selecting pairs for inclusion in the experiments, was to pick those that embodied the most readily available spelling-sound rules.

Eight subjects were assigned to each sequence of the test cards; within each group four went through the cards in forward order and four in backward order. Time to read the two sentences on each card was measured with a stopwatch, and errors in reading the key words were also recorded. The session was tape recorded so that scoring of time and errors could later be checked. After reading the sentences subjects were shown a typewritten list of the exception and regular words and were asked whether they knew the pronunciation and meaning of each word. If a subject was not familiar with a particular word, his or her performance on cards containing that word and its mate was not counted. Of the 36 exception and regular words, an average of 1.3 were unfamiliar to each subject.

Subjects. The subjects were 16 undergraduate students who were paid for their participation.

Results and Discussion

Errors were the major focus in this experiment, since the method of measuring reading times was somewhat informal. In reading the exception word sentences, subjects averaged 7.4 errors, SD = 3.6, on the exception words—an error rate of 11.5%. (The error rate was 20.1% on incorrect exception word sentences and 2.9% on correct exception word sentences.) In all these errors the exception word was pronounced as the corresponding regular word. On the regular word sentences there was a mean of 4.4 errors, SD = 2.9, on the regular words—an error rate of 6.8%. (The error rate was 11.9% on incorrect regular word sentences and 1.8% on correct regular word sentences.) In almost all these errors the regular word was pronounced as the corresponding exception word. Total errors on exception words significantly outnumbered errors on regular words, across subjects $t(15) = 3.00, p < .005$, one tailed, in accord with our hypothesis. A statistical test across items gave the same result, $t(17) = 2.17, p < .025$, one tailed. However, tests across subjects are probably more valid than tests across items in this case, because exception and control sentences were closely matched, and because the pool of potential items was so limited that considerable variance in their power to produce the effect is to be expected.

Averaging across all responses, subjects took an average of 4.3 seconds, SD = .5, to read the cards containing exception word sentences and 4.2 seconds, SD = .5, to read the cards containing regular word sentences. All but four subjects took longer on exception word cards than regular cards, and the difference was statistically significant, across subjects $t(15) = 2.45, p < .025$, one tailed. However, the time difference was not significant when analyzed across the nine sets of cards, $t(8) = .77$.

The results of Experiment 2 show that exception word/regular word differences occur when words are embedded in sentences as well as when they are presented in isolation. That the exception words "should be" pronounced differently, according to the major rules of English, influenced subjects' performance. While subjects certainly knew the correct pronunciation of a word like GREAT, they sometimes misread it as GREET in a context that supported this interpretation—more often than they misread GREET as GREAT. This result suggests that spelling-sound rules are involved in the pronunciation of familiar words in oral reading. While word-specific associations may also play a role, as shown by the fact that subjects did generally produce the standard pronunciations for the exception words, spelling-sound rules have a discernible effect. Therefore, both spelling-sound rules and word-specific associations appear to be involved in the pronunciation process.

Recently, Underwood and Bargh (1982) also reported exception word/regular word differences in naming time when words were presented in isolation and when they followed a congruous or an incongruous sentence. However, their results were limited by the fact that the critical word occurred after the sentence had been presented, rather than as a part of the sentence as in the present study. Also, the regularity effect emerged only for words written in upper case letters.

Experiment 3

Experiment 3 had two goals. The first was to determine whether exception word/regular word differences like those found in Experiment 2 occur when subjects read sentences silently. Such a result would suggest that spelling-sound rules are used, in part, to generate phonological representations in silent reading. To assess use of spelling-sound rules, stimuli like those of Experiment 2 were employed. The procedure, however, was somewhat different. Subjects read each sentence silently and judged whether it was correct or incorrect. The sentences were presented one at a time on a computer screen and response times and errors in the sentence verification task were automatically recorded.

A second goal of Experiment 3 was to measure phonological recoding in silent reading and to relate individual differences in use of spelling-sound rules to individual differences in use of phonological recoding. As we have discussed, phonological recoding in English can occur by use of one or both of two different mechanisms—spelling-sound rules and word-specific associations. If rules are involved, we expect those subjects who show greater use of phonological recoding to show greater use of spelling-sound rules. To measure phonological recoding, we used a sentence verification task involving homophone sentences, a task previously employed by Baron (1973), Baron et al. (1980), Treiman et al. (1981), and Treiman and Hirsh-Pasek (1983). Examples of the sentences used are shown in Table 3. Both the homophone and control sentences are incorrect as written, but the phonological representations of the homophone sentences are correct. If readers recode phonologically they may have difficulty in rejecting these sentences. The matched control sentences are not correct phonologically and should cause no particular difficulty to readers who employ phonological recoding. Note in the first example that the homophone word, BEECH, and the control word, BENCH, both differ from the word that would make the sentence correct (i.e., BEACH) in just one letter. However, BEECH is phonologically identical to the correct word and BENCH is not. Thus subjects who recode phonologically should have more difficulty rejecting the homophone sentence than the control sentence. Indeed, previous studies (even the Baron (1973) study which argued against the importance of phonological recoding) show that errors on homophone sentences significantly outnumber errors on control sentences for hearing readers. A similar trend is found in response times (Baron et al., 1980; Treiman et al., 1981; Treiman & Hirsh-Pasek, 1983).

TABLE 3

Examples of Sentences Used in Experiment 3 to Assess Phonological Recoding

Incorrect sentences	
Homophone sentence	A BEECH HAS SAND.
Control sentence	A BENCH HAS SAND.
Homophone sentence	SHE HAS BLOND HARE.
Control sentence	SHE HAS BLOND HARM.
Correct sentences	
	SCISSORS CAN CUT.
	THE SUN IS SHINING.

Method

Stimuli. Spelling-sound rule task. The stimuli that were employed to assess use of spelling-sound rules in silent reading were similar to those employed in Experiment 2. As in Experiment 2, the sentences were based on pairs of words such as GREAT–GREET and PLAID–PLAYED. A total of 24 pairs were used in Experiment 3, 9 additional pairs having been pretested for possible inclusion following the procedure described for Experiment 2. These pairs are virtually all those in the English language that we, at least, were able to think of. For these pairs, a majority of the subjects who knew both words (an average of 79%) gave the regular word as a possible pronunciation for the exception word. An average of only 13% gave the exception word as a possible pronunciation for the regular word (see footnote 2). The exception words had a median Kučera and Francis (1967) frequency of 29 and the regular words of 38; these values did not differ significantly.

Sentences were generated from these word pairs as in Experiment 2. There were two forms of the experiment that differed in the sentence frames used. Each form contained 96 sentences—4 generated from each exception–regular pair. The sentences were slightly shorter than those of Experiment 2, ranging from 4 to 8 words in length. They are listed in the Appendix. Fourteen practice sentences were also constructed.

Phonological recoding task. The stimuli that were employed to assess use of phonological recoding in silent reading were based on 28 pairs of homophone and control words, as shown in the Appendix. The homophone and control words were approximately equally similar to the correct word in number and position of different letters. Their median frequencies were 37 and 18, respectively (Kučera & Francis, 1967), and did not differ significantly. There were two forms of the experiment that differed in the sentence frames used. Each form contained 28 homophone sentences and 28 control sentences. All these sentences were incorrect. Each form also contained 56 correct sentences. The homophone and control sentences ranged from three to nine words in length, and the correct sentences were comparable. Fourteen practice sentences were also constructed.

Procedure. The subjects sat before the computer screen, resting their index fingers lightly on two response keys. They were instructed to read each sentence silently and to push the right-hand key if it was a correct, acceptable sentence of English. They were to push the left-hand key if it was an incorrect, unacceptable sentence. The instructions stressed speed of response over accuracy. The sentences were presented one at a time, with a blank screen interval of 2 seconds between successive sentences. Subjects could obtain a longer break by pressing a third response key marked "Rest". For each task, the practice sentences were presented first in a fixed order, followed by the test sentences. The order of test sentences was independently and randomly determined for each subject, and all sentences in each form were presented twice.

Subjects did both forms of the spelling-sound rule task in one session, with order of forms balanced across subjects. After completing the spelling-sound rule task, subjects were shown a typewritten list of the exception and regular words and were asked whether they knew the pronunciation and meaning of each word. If a subject was not familiar with a particular word, his or her performance on sentences containing that word and its mate was not counted. Of the 48 exception and regular words, an average of 1.1 were unfamiliar to each subject.

In a separate session subjects did both forms of the phonological recoding task, with order of forms balanced across subjects. Order of tasks was also balanced across subjects. After completing the phonological recoding task, subjects were shown a typewritten list of all the homophone sentences. They were asked whether any of the sentences contained words of whose spelling they were unsure. If a subject was unsure of the spelling of a particular homophone word, and consequently unsure whether the resulting homophone sentence was correct or incorrect, his or her performance on sentences containing that homophone-control pair was not counted. The average number of homophone words that were thus deleted for each subject was 1.8.

Subjects. The subjects were 31 undergraduate students who were paid for their participation.

Results and Discussion

Spelling-sound rule task. There were no differences between the two forms of the experiment, so the results are pooled across forms. Consistent with the stress on speed in the instructions, the error rate was relatively high. Analyses of the errors showed that subjects made an average of 14.1 errors, SD = 10.6, on the exception word sentences—an error rate of 8.0%. They averaged 12.5 errors, SD = 10.6, on the regular word sentences—an error rate of 7.1%. This difference was statistically significant when tested across subjects, $t(30) = 1.91$, $p < .05$, one tailed. The difference in response times was in the same direction: a mean of 1.70 seconds, SD = .45, averaged over all responses on the exception word sentences and 1.68 seconds, SD = .44, on the regular word sentences. The time difference did not reach significance, $t(30) = 1.38$, $p < .1$ one tailed. When statistical tests were done across items, the differences between exception word sentences and regular word sentences were not significant, although the error difference approached significance, for errors $t(23) = 1.33$, $p < .1$, one tailed; for times $t(23) = .96$. As in Experiment 2, however, tests across subjects are probably more valid than tests across items, since virtually all of the possible exception word–regular word pairs were used. Thus, these results suggest that exception word sentences were more difficult than regular word sentences, consistent with the hypothesis that phonological recoding via spelling-sound rules occurs in silent reading. Further support for this hypothesis will be presented below.

Phonological recoding task. As in the spelling-sound rule task, there were no differences between the two forms. Consistent with the stress on speed of response, the error rate was relatively high. On the homophone sentences subjects averaged 11.6 errors, SD = 6.1—an error rate of 10.5%. These errors, of course, were incorrect acceptances of homophone sentences. The average number of errors on the matched control sentences was only 4.9, SD = 4.3. This translates into an error rate of 4.5%. The difference in number of errors on the two types of sentences was highly significant, across subjects $t(30) = 7.90$; across items $t(27) = 4.30$; for both $p < .0005$, one tailed. A difference was also found in response times to the two types of incorrect sentences. Response times to homophone sentences averaged 1.58 seconds, SD = .44; response times to control sentences averaged 1.46 seconds, SD = .39. This difference was statistically significant, across subjects $t(30) = 4.28$; across items $t(27) = 4.06$, for both $p < .005$, one tailed. These results replicate previous results with the homophone sentence task (Baron, 1973; Baron et al., 1980; Treiman et al., 1981; Treiman & Hirsh-Pasek, 1983). As mentioned above, even the Baron (1973) study, which is often cited as evidence against phonological recoding, did find that subjects made significantly more errors on homophone phrases than control phrases. In fact, Baron (1973) concluded that a phonological code is used "at least some of the time by some subjects," an interpretation that is not inconsistent with the present findings.

Relation between the two tasks. Subjects who used a greater degree of phonological recoding, as reflected in the homophone sentence task, tended also to show a greater regularity effect. Extent of phonological recoding was measured by a composite score that took into account both time and error differences between homophone and control sentences. This composite score was

$$z(E_H - E_C) + z\left(\ln \frac{T_H}{T_C}\right),$$

where E_H is number of errors on homophone sentences, E_C is number of errors on control sentences, T_H is response time on homophone sentences, and T_C is response time on control sentences. The measure of the regularity effect was analogous.[3] The correlation between these two measures was significantly positive, $r = .33$, $t(29) = 1.88$, $p < .05$, one tailed, suggesting that use of spelling-sound rules in silent reading of sentences is greatest among those readers who show a substantial degree of phonological recoding. Further, for those subjects who exceeded the median in our measure of phonological recoding in the homophone task, exception word sentences produced significantly more errors than regular word sentences, whether tested across subjects, $t(14) = 1.90$, $p < .05$, one tailed, or across items, $t(23) = 1.91$, $p < .05$, one tailed. These results support the hypothesis that readers who recode phonologically do so, in part, through use of spelling-sound rules.

General Discussion

The present experiments have studied phonological recoding in reading tasks involving complete sentences. These tasks are closer to many real-life reading situations than are the lexical decision tasks used in much previous research. Although the sentences used here may not be completely representative of sentences found in text, they are surely more representative than are the isolated words of earlier studies. Experiments 1 and 3, which concerned silent reading, found that phonological effects previously noted with isolated words are also found when words are embedded in sentences. First, the phonological relation between visually similar words affects performance in a sentence-reading task as it does in a lexical decision task (Meyer et al., 1974; Shulman et al., 1978). Second, the conformity of words to spelling-sound rules affects performance, as previously noted for lexical decision (Barron, 1980; Stanovich & Bauer, 1978). These findings, by showing that phonological characteristics of printed words influence subjects' performance, provide clear evidence for phonological recoding in the reading of sentences. Thus, along with the results of the homophone sentence task of Experiment 3, they add to the evidence cited earlier for phonological recoding. Further, these findings are consistent with the view that the phonological codes involved in silent reading are derived, in part, by use of spelling-sound rules. In oral reading, too, the results of Experiment 2 suggest that pronunciations of written words are derived in part by spelling-sound rules. Sentences containing exception words are more difficult to read aloud than sentences containing regular words, just as individual exception words are more difficult than individual regular words (Baron & Strawson, 1976; Gough & Cosky, 1977; Stanovich & Bauer, 1978).

The decrement on exception word sentences relative to regular word sentences appeared greater in the oral reading task of Experiment 2 than in the silent reading task of Experiment 3. That is, spelling-sound rules may play a larger role in oral reading than in silent reading. This difference makes sense if we assume that use of spelling-sound rules can emerge only when readers access the phonological forms of printed words. Access to phonological forms is of course obligatory in oral reading, whereas it is optional in silent reading. Thus, use of spelling-sound rules in silent reading ought to be most prevalent among readers who use a substantial degree of phonological recoding, as we found in Experiment 3.

The magnitude of the effects found here probably underestimates the degree to which people rely on spelling-sound rules in reading sentences in text. The confusion effect shown in Experiment 1 *need* not

[3] A log transform of times was used in an attempt to avoid spurious correlations that arise because of differences among subjects in overall speed. If we assume that the increase in time for homophone sentences relative to control sentences, or for exception word sentences relative to regular word sentences, is proportional to a subject's speed on control or regular word sentences, then use of logs will eliminate the effect of overall speed.

occur at all, even if reliance on rules were total. Readers could simply ignore early words in a sentence in decoding later ones. Likewise, the difficulty on exception words shown in Experiments 2 and 3 probably underestimates subjects' use of rules. Only one or two letters in each exception word were pronounced in deviant fashion; the remaining letters could be, and may well have been, pronounced by using rules. Finally, the sentences used in these experiments were relatively short in comparison to many sentences found in text. Longer sentences might be expected to place greater demands on working memory, and therefore encourage the use of phonological recoding to a greater degree than the sentences used here.

In addition to questions about the degree of reliance on spelling-sound rules, questions about the way in which these rules are used also remain to be answered. Readers could use rules to help derive the phonological representation of a printed word as part of the process of identifying the word's meaning. This would be a prelexical process. Alternatively or additionally, readers could use rules postlexically to derive the phonological form of an already identified word. Such a process might be used when storing words in memory. The present results do not allow us to distinguish between prelexical and postlexical processes.

Previous studies have shown that spelling-sound rules play an important role in learning to read an alphabetic system. Firth (1972), for example, found that ability to decode nonsense words accounted for about 75% of the variance in reading ability among a group of 91 six-year-olds. Baron and Treiman (1980) selected pairs of children who were approximately equal in reading ability, but such that one child was younger by two years. The younger children—those who had reached the given reading level more quickly—were more likely to be Phoenician readers than the older children. This result suggests that skill at spelling-sound rules contributes importantly to rate of reading acquisition. Further support for this claim is that most children who are identified as severely reading disabled are Chinese-style readers, weak at spelling-sound rules (Boder, 1973; Snowling, 1980). Relatively few show a Phoenician style of reading.

The present results complement the previous studies of beginning readers by showing that spelling-sound rules continue to be important for adults. Fluent adult readers use these rules even when reading familiar words and even when reading silently. They do not rely completely on word-specific associations, as might have been expected. Of course, word-specific associations must play some role for both adults and children, due to the many exceptions to the rules that exist in English. And, even if all phonological recoding *did* occur via spelling-sound rules, phonological recoding is itself not obligatory. Nonetheless, our results suggest that adult readers continue to use spelling-sound rules. Even if a person managed to learn an alphabetic system without these rules—and given the evidence cited earlier we doubt that this would be easy—this person would not become a fluent reader.

APPENDIX

Stimuli for Experiment 1

Sentences based on similar spelling/different pronunciation critical pairs: The alternate words are given in parentheses, and the sentence completion choices are given at the end.

The man with the beard (goatee) heard (listened to) her	escaped/sing
Before I cheated (lied) I sweated (perspired)	remark/profusely
The chorus (singing group) has chores (tasks) for new	members/summer
You copy (duplicate) dopy (stupid)	messages/help
He made a nasty (mean) hasty (rash)	remark/profusely

The fanatic (frenzied) lunatic (madman) has	escaped/sing
We can truly (certainly) call July (June)	members/summer
The rapist (criminal) saw the therapists (doctors) for	messages/help

Sentences based on similar spelling/similar pronunciation critical pairs: The alternate words are given in parentheses, and the sentence completion choices are given at the end.

I will never (not) sever (destroy) our	relationship/you
That brown (purple) gown (dress) is	expensive/school
She took (removed) a book (pamphlet) from the	grey/shelf
I hate (don't like) to be late (tardy) for	expensive/school
My shirt (jacket) has dirt (a stain) on	it/attic
The mouse (rat) in our house (home) is	grey/shelf
Bring (carry) string (rope) with	relationship/you
The carpenter hoards (saves) boards (planks) in his	it/attic

Stimuli for Experiment 2

The exception word and regular word are given first, followed by the two sentence frames.

coup, coupe

The generals staged a bloody ________ and took power.
The man bid on an antique ________ at the auction.

none, known

Unfortunately, ________ of the delicious candy is left.
Chaplin's films are ________ all over the world.

word, ward

The father gave his son a ________ of advice.
She works in the maternity ________ of the hospital.

seize, size

The pirates will ________ command of the ship.
What ________ shirt do you wear?

shoe, show

The tight ________ hurt her foot.
Will you ________ me your new dress?

come, comb

You should ________ to the party.
You should ________ your hair.

great, greet

George Washington was a ________ leader.
The hostess came down to ________ her guests.

Sean, seen

Someone named ________ O'Casey is likely to be Irish.
I haven't ________ my aunt and uncle in two years.

doll, dole

The little girl put her ________ to bed.
They had lived on the ________ for many years.

height, hate

He was six feet in ________ and very thin.
The boy used to ________ his father but now he doesn't.

ski, sky

We will ________ in Vermont this winter.
The night ________ was filled with stars.

one, own

She has a ________ room apartment.
She has her very ________ room.

sew, sue

The button fell off. Can you ________ it back?
If you don't return my money I'll ________ you.

been, bean
The children have ______ playing all day.
He is as skinny as a ______ pole.

sweat, sweet
He worked up a ______ while running.
The candy left a ______ taste in my mouth.

water, waiter
We can go skating when the ______ on the lake freezes.
We can eat when the ______ brings the food.

are, air
Who ______ all these people?
The ______ is quite polluted.

sleight, slate
The magician was good at ______ of hand.
The children wrote on ______ tablets.

Stimuli for Spelling-Sound Rule Task of Experiment 3

The exception word and regular word are given first, followed by the two sentence frames used in one form of the experiment and the two sentence frames used in the order form of the experiment.

coup, coupe
The generals staged a ______ .
The car is a ______ .
The attempted ______ was blocked.
The antique ______ is black.

one, own
Count from ______ to ten.
That's my very ______ room.
Which ______ do you want?
Landlords ______ many houses.

word, ward
He never said a kind ______ .
We vote in the first ______ .
"Mama" was his first ______ .
She works in the maternity ______ .

seize, size
The pirates will ______ command.
Tell me what ______ you wear.
You must ______ that opportunity.
Those are jumbo ______ eggs.

shoe, show
The tight ______ hurt her foot.
Will you ______ me your car?
The heel of his ______ was loose.
We saw a Broadway ______ last night.

come, comb
Trains never ______ on time.
Neat people ______ their hair.
Here ______ the kids.
The barber's ______ was lost.

great, greet
Lincoln was a ______ man.
A host must ______ his guests.
I had a ______ time dancing.
I had to ______ the visitors.

water, waiter
The glass contained ______ .
The diner summoned the ______ .
Frozen ______ is called ice.
The ______ brought the food.

chic, chick
She's wearing a ______ French dress.
The baby ______ ate grain.
A person who is stylish is ______ .
A young bird is a ______ .

height, hate
He was six feet in ______ .
The opposite of love is ______ .
What is the ______ of the building?
He used to ______ his teacher.

been, bean
The boys have ______ playing.
Jack climbed the ______ stalk.
I don't know where she's ______ .
He's as thin as a string ______ .

sew, sue
If your pants rip, ______ them up.
If they don't pay, ______ them.
I'll ______ some clothes.
I'll ______ for damages.

ski, sky
We will ______ this winter.
The night ______ was starry.
They love to ______ .
Birds fly in the ______ .

none, known
The choice is all or ______ .
The actor is well ______ .
There are ______ left.
Have you ______ her long?

are, air
I'm older than you ______ .
There's dust in the ______ .
My relatives ______ visiting.
We need an ______ conditioner.

sleight, slate
Magicians are good at ______ of hand.
The boys wrote on ______ tablets.
I was tricked by his ______ of hand.
The old house had a ______ roof.

sweat, sweet
The athlete worked up a ______ .
The candy tasted ______ .
Runners often ______ a lot.
She craves ______ desserts.

Sean, seen
A man named ______ must be Irish.
I have not ______ you in years.
She loved ______ O'Casey.
He's never ______ the ocean.

wear, we're
That's what I ______ to work.
We'll call if ______ coming.
Hard work can ______ you out.
At last ______ all alone.

bear, beer
If you see a grizzly ______ , run away.
If we drink more ______ , we'll get drunk.
At the stoplight, ______ right.
Ale is like ______ , only stronger.

plaid, played
He wore a ______ shirt.
The children ______ outdoors.
The scarf was Scottish ______ .
The music was well ______ .

pear, peer
My favorite fruit is a ______ .
A person of equal rank is a ______ .
I got a partridge in a ______ tree.
He is well liked by his ______ group.

corps, corpse
He enlisted in the Marine ______ .
A dead body is a ______ .
He joined the drum and bugle ______ .
The coffin contained a large ______ .

fete, feet
A ______ is a fair.
His ______ are narrow.
I had fun at the ______ .
He had sneakers on his ______ .

Stimuli for Phonological Recoding Task of Experiment 3

False sentences: The homophone word and control word are given first, followed by the sentence frame used in one form of the experiment and the sentence frame used in the other form of the experiment.

sun, sin
A ______ is male.
The ______ works for his father.

soul, soil
______ is a kind of fish.
The filet of ______ was tasty.

ore, orb
An ______ is used for rowing.
An ______ is used to steer a boat.

rein, ruin
A ______ can be a downpour.
Don't stand in the pouring ______ .

hare, harm
______ is on the head.
She had blond ______ .

air, ear
An ______ can inherit money.
The ______ will inherit the estate.

male, malt
Letters and postcards are ______ .
You can't ______ a letter without a stamp.

beech, bench
A ______ has sand.
I live in Miami ______ .

beat, belt
A ______ is a red vegetable.
A ______ is a kind of vegetable.

sales, salts
Boats may have ______ .
The boat's ______ fluttered in the wind.

bow, bog
A ______ is an admirer.
Her ______ asked for her hand in marriage.

doe, dot
Bread is made from a ______ .
Uncooked batter is called ______ .

gate, gain
A person's way of walking is his ______ .
When he ran, his ______ was jerky.

pain, pawn
A ______ is part of a window.
The window ______ was made of glass.

plane, plant
A ______ is where cattle graze.
The opposite of fancy is ______ .

beet, bead
A ______ is a measure of rhythm.
They ______ the prisoner with a club.

cent, scene
A ______ is a smell.
An odor is a ______ .

site, sigh
A blind man has lost his ______ .
A person with no sense of ______ is blind.

pair, pier
A ______ is a kind of fruit.
A ______ is a delicious fruit.

fur, fire
______ is a kind of tree.
______ trees are green all winter.

loot, lift
The ______ is a musical instrument.
The ______ is a stringed instrument.

stares, starts
______ are in a house.
Climb the ______ .

cord, chore
Three tones form a ______ .
Play an A minor ______ on the guitar.

beach, belch
A ______ is a kind of tree.
An old ______ tree grew in the yard.

tale, talk
A ______ is on an animal.
The dog wagged its ______ .

pane, pair
A ______ is a hurt.
After my operation I was in ______ .

plain, plate
A 747 is a ______ .
I will travel by ______ .

pear, pail
Two things are a ______ .
A ______ is a group of two.

Correct sentences: A subset of the correct sentences is shown below.

An infant is young.
Wine is a beverage.
A cane can be used for walking.
Snow is cold.
Fingers are part of the body.
A woman is female.
Lamp gives light.
Houses can be made of wood.

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