Phonological recoding in lexical decision: Effects of spelling-to-sound regularity depend on how regularity is defined

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This study is concerned with two contrasting accounts of lexical access in reading: phonological recoding and direct access. Experiment 1 demonstrated that exception words that have a guide to their pronunciation listed in the *Oxford Paperback Dictionary* (e.g., GAUGE) gave rise to longer lexical decision times than matched regular words (e.g., GRILL). Experiment 2 contrasted three types of words: exceptions that have dictionary-listed pronunciations, exceptions without listed pronunciations, and regular words. Lexical decision responses to the first type were significantly longer than those produced to the other two types. Nonlisted exception words, however, did not differ from regular words. Experiment 3 confirmed the results of Experiment 2, using pronunciation speed as the dependent measure. Experiment 4 showed that the slower lexical decision times associated with dictionary-listed exception words remain when subjects are given speeded-response instructions. In contrast to earlier studies of a similar kind, these results indicate the existence of a phonological recoding stage in reading. Furthermore, they suggest that the phonological recoding system is more flexible than was previously thought.

Over the last few years, two fundamental theories have emerged to explain how printed words gain access to the mental lexicon (McCusker, Hillinger, & Bias, 1981). The first of these, phonological recoding, asserts that the printed word is first transformed into some representation of its sound, which in turn serves as a basis for lexical access (e.g., Meyer, Schvaneveldt, & Ruddy, 1974; Rubenstein, Lewis, & Rubenstein, 1971). The alternative theory is that lexical access is direct and achieved solely on the basis of visual analysis (e.g., Frederiksen & Kroll, 1976).

In a recent article, Coltheart, Besner, Jonasson, and Davelaar (1979) have argued that the most appropriate experimental task for evaluating these two theories is the lexical decision task (Meyer & Schvaneveldt, 1971), in which the subject has to decide whether a given string of letters is or is not a word in the English language. The advantage of this task is that, with the provision of

appropriate controls (cf. James, 1975), performance of the task must require lexical access.

On the basis of Coltheart's (1978) review of the area, Coltheart et al. (1979) have asserted that the only plausible basis for a phonological recoding system is one based on "grapheme-to-phoneme correspondences" (GPCs). GPCs operate by breaking down a word into its constituent graphemes and assigning each one its appropriate phonemic description. However, as Coltheart et al. point out, one of the principal difficulties in operating any phonological recoding system is the considerable inconsistency in English spelling-to-sound correspondences. Consider, for example, the vowel digraph EA, which can be assigned several different phonemic descriptions (e.g., BREAD, SEAL, STEAK, CREATE). For this reason, any recoding system based on GPCs is going to have considerable difficulty in assigning the correct phonemic description to a large number of English words.

Nonetheless, Coltheart et al. (1979) have argued that such difficulties can be overcome to a large extent, since it is possible to produce a set of GPCs that work for most words (i.e., in the absence of specific lexical information, such a set of rules would assign the correct pronunciation to the majority of English words). Coltheart et al. suggested that these GPCs might resemble the pronunciation rules produced by Wijk (1966) and, more recently, Venezky (1970). In the 1970 survey, Venezky presents the spelling-to-sound correspondences for basic English vowel and consonant patterns. For each graphemic unit, Venezky lists the major phonemic correspon-

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dence and the various minor correspondences. Thus, for EA, SEAL represents the major correspondence and BREAD, STEAK, and CREATE represent minor correspondences.

In order to investigate the possible involvement of a GPC-based recoding system in reading, Coltheart et al. (1979) carried out two experiments in which lexical decision times to "regular" and "exception" words were measured. Exception words were defined as those words containing a minor correspondence (e.g., STEAK, GLOVE, BLOOD, BROAD, PINT). The rationale of these experiments was that if GPC-based recoding did occur during lexical decision, then exception words should take longer to identify than words containing major correspondences.¹

However, the results of the experiments failed to obtain any support for the phonological recoding hypothesis. Lexical decision times to the two types of words did not differ significantly, and the error rates were similar. On the basis of these findings, it was concluded that "when a word is presented to a subject in a lexical decision task access to that word's lexical entry never depends on a prelexical phonological recoding" (Coltheart et al., 1979, p. 501). Furthermore, Coltheart et al. extended their argument to conclude, by implication, that the basic process of lexical access in normal reading did not involve a phonological stage either.

The impetus for the present series of experiments came from my initial attempt to confirm the Coltheart et al. (1979) findings. In constructing the stimulus materials, it was decided to use, as a starting point, the exception words used by Coltheart et al. and those from the earlier pronunciation study of Baron and Strawson (1976). On examining these materials, I experienced doubt as to whether some of the exception words used in these studies were particularly exceptional in their pronunciation.² Coltheart et al., for example, included the word SIGN in their sample of exceptions. While it is true to say that, overall, the correspondence of I to [ai] is an exception, it does not appear to be so when followed by GN at the end of a word (Venezky, 1970, p. 113). Similarly, the Baron and Strawson sample contained several exception words beginning with W (e.g., WATER, WATCH, and WOMAN). However, Venezky (p. 112) notes that major spelling-to-sound correspondences do not often apply to vowel sounds preceded by W. Given this situation, it may well be incorrect to assert that such words do contain exceptional pronunciations, since they could conform to more specific rules concerning the influence of the letter W.

Because of these problems, it was decided to seek additional confirmation of a given word's irregularity in pronunciation. Although most dictionaries were inadequate for this purpose, since they listed the pronunciations of all words, one recently published British work, the *Oxford Paperback Dictionary* (1979; from here on, this will be referred to simply as "the dic-

tionary"), lists a pronunciation only for any word that "is difficult to pronounce, or difficult to recognise when read." It seemed, therefore, that this dictionary could provide a useful basis for confirming that a particular word was or was not exceptional in its pronunciation.

As a first step, it was decided to look up the various exception words used by Baron and Strawson (1976) and Coltheart et al. (1979). Somewhat surprisingly, it was found that the dictionary listed the pronunciations of only 30% of the Coltheart et al. words and only 10% of the Baron and Strawson words. Although the full implications of this will be considered later, it is sufficient to say that the absence of a pronunciation guide for the majority of exception words used in previous studies suggested the possibility that a subject's ability to attribute the correct phonological code to a given graphemic representation might be more flexible and extensive than the rule system provided by the Venezky (1970) study. In short, while the Venezky rules provide a good description of English spelling-to-sound rules, they might well represent only part of the actual knowledge possessed by a fluent reader of the language.

Accordingly, Experiment 1 investigated lexical decision times to exception words and regular words with the added provision that each exception word should have a pronunciation guide listed in the dictionary.

EXPERIMENT 1

Method

Subjects. The subjects were eight members of the staff and student population of the University of Sussex, and they were paid for their participation.

Materials. Thirty exception words were selected on the basis that they possessed a minor correspondence as defined by the Venezky (1970) rules and, additionally, had their pronunciation listed in the dictionary (these are from now on referred to as OPD words). For each of these, a regular word (R word) was also selected. Each pair was matched for frequency (Kučera & Francis, 1967), part of speech, number of letters, and, in most cases, number of syllables.³ The stimuli are shown in Appendix A. Sixty lawful nonwords were also constructed by substituting one letter of a common real word (e.g., CAKE-DAKE). Care was taken to avoid the construction of pseudo-homophones. Each stimulus was typed in uppercase letters and photographed onto transparent Xerox paper and mounted in a standard 35-mm slide mount.

Procedure and Apparatus. The words and nonwords were divided into two lists (A and B), each containing 15 OPD words, 15 R words, and 30 nonwords. Each list was then randomly rearranged to form the experimental sequence. In addition to the 60 experimental items, four "dummy" items were included at the beginning of each sequence. Half the subjects received List A first and half, List B.

Subjects were seated in a soundproof room in front of a back-projection screen that was blacked out apart from a small viewing slot. The stimuli were presented by means of a Kodak Carousel projector and subtended a visual angle of approximately 2 deg. Each stimulus was presented for 1.6 sec, with an interstimulus interval of 2.5 sec. A warning tone preceded the onset of each trial, and projection time was synchronized via a tachistoscopic shutter linked to an electronic timing apparatus.

Subjects were informed that they were taking part in an

experiment concerned with reading. Each trial would involve the presentation of a letter string, and they should decide as quickly as possible whether or not the string was a word in the English language. Subjects made their responses by means of two response buttons, and all made "yes" responses with their preferred hand. As a precaution against subjects' making too many errors, subjects were informed that, although all the words are familiar, some are less common in print than others. Thus, if they tried to respond too fast, they would make too many errors. Subjects were given 12 practice trials and then proceeded to the first experimental list. A short rest interval separated the two lists.

Results

The mean correct lexical decision time was 753 msec for R words and 832 msec for OPD words. Two sets of scores were computed for each of these conditions, one by collapsing across subjects and the other by collapsing across words. The individual word means are shown in Appendix A. Separate analyses of variance were performed on these two sets of data, and the resulting F ratios were combined to calculate a min F' analysis (Clark, 1973). This analysis showed that lexical decision speeds were significantly slower in the OPD condition [$\min F'(1,26) = 4.2, p < .05$]. As there were only 14 errors made in total, no analysis of errors was made.

Discussion

The results of Experiment 1 showed that OPD words produced significantly longer lexical decision latencies than R words, a finding consistent with the existence of a phonological recoding stage in lexical decision. However, these results did not rule out the possibility that the current experimental situation might also facilitate longer lexical decision times to exception words whose pronunciations are not listed in the dictionary. To investigate this, a second experiment was devised in which three types of real words were investigated: OPD, R, and MC. The last category represented words containing a minor correspondence whose pronunciations were not listed in the dictionary. Many of these words were taken from the samples of exception words used by Baron and Strawson (1976) and Coltheart et al. (1979).

EXPERIMENT 2

Method

Subjects. The subjects were 18 members of the staff and student population of the University of Sussex, none of whom took part in Experiment 1. They were paid for participation.

Materials. Thirty-three OPD words were selected. For each of these, an R word and an MC word were also chosen. Each of these triples were matched for word frequency and part of speech. Because of the constraints on material selection and the need to maintain a large sample, some triples were not matched exactly for number of letters, although in these cases the deviation was only one letter. These stimuli are shown in Appendix B. In addition, 99 nonwords were constructed along the same lines as the nonwords in Experiment 1.

Procedure and Apparatus. The apparatus and general procedure were the same as those in Experiment 1. The words and nonwords were divided into three lists, each containing 11 OPD

words, 11 R words, 11 MC words, and 33 nonwords. The lists were presented in a counterbalanced order to ensure that each list was tested an equal number of times in first, second, and third position. Two randomizations of each list were used.

Results

The data were calculated and analyzed in a manner similar to Experiment 1. The mean lexical decision time for MC words was 688 msec, for R words, 709 msec, and for OPD words, 741 msec. The individual word means are shown in Appendix B. The analysis revealed a significant main effect of word type [$\min F'(2,141) = 3.919, p < .05$]. Because no method exists for post hoc comparisons using the min F' statistic, separate Newman-Keuls analyses were undertaken for the word-based and subject-based analyses. Both of these indicated that the only significant differences were between the OPD and R conditions and the OPD and MC conditions (all differences significant at the 5% level). There were totals of only 16, 18, and 21 errors in the MC, R, and OPD conditions, respectively, once again precluding any analysis of errors.

Discussion

The results of Experiment 2 showed that OPD words took longer to identify than either R or MC words but that the latter two did not produce significantly different lexical decision times. This finding provided a strong indication that the longer lexical decision times found with OPD words did not arise from the presence of minor correspondences per se. Rather, it seems that positive evidence for phonological recoding is evident only in the processing of words with spelling-to-sound correspondences unusual enough to warrant inclusion in the dictionary.

Experiment 3 followed up the results of Experiment 2 by examining how OPD, R, and MC words behaved in a pronunciation task. Coltheart et al. (1979) have argued that such a task is a useful means of establishing that a group of words do have exceptional pronunciations, since, if this is the case, those words should produce longer pronunciation times (cf. Baron & Strawson, 1976; Stanovich & Bauer, 1978). In Experiment 3, therefore, subjects were given lists of OPD, R, or MC words and were asked to read them aloud as quickly as possible.

EXPERIMENT 3

Method

Subjects. Twelve undergraduates from Goldsmiths' College served as unpaid volunteers.

Materials. Materials were the same as those in Experiment 2, except that the triple WALLOP-DANGLE-INDICT was excluded. This was to enable the construction of two lists of 16 items for each of the three types of words.

Procedure and Apparatus. The OPD, R, and MC words were each divided into two lists of 16. Subjects were asked to read out each list as quickly as possible. Appropriate counterbalancing of

the lists was employed. Reading times were recorded by means of a manually activated millisecond timer.

Results

The mean list pronunciation time for OPD words was 10.85 sec, for R words, 9.33 sec, and for MC words, 9.56 sec. A by-subjects analysis of variance revealed a main effect of word type [$F(2,22) = 4.86, p < .05$]. Newman-Keuls comparisons revealed that the only significant differences were between OPD and R words and OPD and MC words (all differences significant at the 5% level or better).

Discussion

Experiment 3 demonstrated that OPD words took longer to pronounce than either R or MC words, but that the last two did not differ. These results, therefore, indicate that even though MC words possess a minor correspondence, this does not significantly slow down the time taken to pronounce them.

The results reported so far indicate quite clearly that phonological recoding does take place in two types of laboratory reading task. Moreover, they suggest that the phonological recoding system used is not adequately characterized by the Venezky (1970) GPC rules, since possession of a minor GPC *per se* does not appear to be a sufficient condition for the emergence of phonological recoding effects.

Before discussing the implications of Experiments 1, 2, and 3, a final experiment will be described concerning the findings of Bauer and Stanovich (1980) and Stanovich and Bauer (1978). Bauer and Stanovich have proposed that phonological recoding effects emerging from manipulations of spelling-to-sound regularity arise because subjects adopt some form of postlexical rechecking strategy. In their first paper, Stanovich and Bauer (1978) suggest that lexical access is first achieved via direct visual access. However, as an additional check on a letter string's authenticity, lexical decision is held up until the products of a more slowly developed phonological code also become available. This code, which is presumably the result of nonlexical recoding rules, will, in the case of exception words, produce an erroneous input that will either delay processing or result in an incorrect lexical decision.

However, in the subsequent study, Bauer and Stanovich (1980) seem to favor an interpretation based on a process in which rechecking is based on an item's lexically derived phonemic description. This alternative view arises because of Bauer and Stanovich's adoption of Glushko's (1979) "activation-synthesis" model to account for the effects of spelling-to-sound regularity on lexical decision speed. This model proposes a distinction between "consistent" and "inconsistent" words, the former being those with visually similar neighbors that share the same pronunciation (e.g., LINK, PINK) and the latter being word sets in which there is at least

one deviation (e.g., SAVE, HAVE). According to the model, access to the lexicon from the printed word is achieved initially by visual analysis, with the word's phonemic description becoming available subsequent to lexical access. Furthermore, activation of a word's lexical entry also activates visually similar words and their phonemic representations. This mechanism has important consequences for the pronunciation latency, since consistent words will activate neighbors with similar pronunciations, thus facilitating production, whereas inconsistent words will activate some conflicting phonemic information that will disrupt production, a finding confirmed by Glushko's data.

Bauer and Stanovich (1980) extend Glushko's (1979) theory by asserting that "what gives rise to the regularity effect . . . is not spelling-to-sound rules, but rather the consistency or inconsistency of the set of words activated by the target word" (p. 429), the assumption being that most regular words will be consistent, whereas most irregular words will be inconsistent (although see below). It is notable, however, that Bauer and Stanovich do not offer any explanation of how the differential activation patterns of consistent and inconsistent words would actually lead to differences in lexical decision speed. One could suggest that the recheck consists of a comparison of the activated word's phonemic code with those of its visual neighbors, with confidence, and hence response speed, being dependent on the degree of commonality. This does, however, seem a little counter-intuitive, since, in order to carry out such a recheck, one must already be at a lexical entry and, as a result, have sufficient information for a lexical decision.

Additionally, the empirical basis of the latter explanation is rather weak. It stems from an experiment in which Coltheart et al.'s (1979) regular words were used but reclassified in terms of the consistent-inconsistent distinction (Bauer & Stanovich, 1980, Experiment 2). The results showed that regular inconsistent words (e.g., SPEAR) produced significantly longer lexical decision latencies than regular consistent words (e.g., CHECK). On the basis of these data, Bauer and Stanovich suggest that Coltheart et al.'s failure to obtain a regularity effect could be explained by the fact that they failed to take account of consistency when constructing their regular words.

However, this conclusion is dubious for a number of reasons. First, the experiment carried out used only nine exemplars of each word type, hardly sufficient to control for the existence of other factors that might influence decision speed. Second, Bauer and Stanovich (1980) failed to find a significant difference between regular consistent words and exceptions, which are presumably inconsistent too. Finally, if, as Bauer and Stanovich suggest, the "effect [of regularity] is due to the nature of the activated neighbourhoods of consistent and inconsistent words" (1980, p. 429), then it is surprising that their Experiments 3 and 4 achieved such a

reliable regularity effect when 25% of their regular words are inconsistent, using as a definition the existence of visually similar but nonrhyming neighbors (p. 425). In addition, using the same definition, 11% of their exception words were actually consistent.⁴

The results of the present Experiment 2 also argue strongly against the possible influence of the consistent-inconsistent distinction on lexical decision speed. If one examines the items composing the MC target list (Appendix B), then it is clear that most, if not all, would, under Glushko's (1979) definition, be classified as inconsistent. The results, however, showed that lexical decision times tended to be slightly faster in the MC condition. A finer analysis involving only the 16 monosyllabic pairs of items reveals a mean lexical decision time for MC words of 682 msec and for R words, a value of 693 msec, a difference that was not significant ($F < 1$). It would seem, therefore, that the consistent-inconsistent distinction does not underlie the known effects of spelling-to-sound regularity on lexical decision. Thus, in the absence of any alternative account, it seems more reasonable to assume that the phonological recoding effects observed in these and other experiments arise through the application of nonlexically based recoding rules.

Notwithstanding these problems, it is important to consider more closely the evidence upon which Bauer and Stanovich (1980) and Stanovich and Bauer (1978) base their general claim that phonological recoding effects are postlexical. First, they assert that if prelexical recoding effects exist at all, they should emerge more strongly under conditions of stimulus degradation, the argument being that "such manipulations (i.e. degradation) should increase the dependence of lexical access on the phonological route" (Bauer & Stanovich, 1980, p. 429). To test this prediction, Bauer and Stanovich report several experiments in which the processing of regular and irregular words is compared under normal and degraded conditions (including one experiment in which the visual quality of target items is impaired by the use of alternating case). In every case, Bauer and Stanovich found no support for the above prediction by demonstrating the absence of an increased advantage for regular words under degraded conditions.

Unfortunately, a considerable flaw exists in the logic of these experiments. According to Bauer and Stanovich (1980), phonological recoding should become more predominant because the visual route is impaired by degradation. However, in asserting this, Bauer and Stanovich ignore the obvious point that the development of a phonological code from a printed word must itself be dependent on the quality of the letter string. If this is the case, and Bauer and Stanovich offer no evidence to the contrary, then there is no basis for predicting an increased effect of spelling-to-sound regularity under degraded conditions. Clearly, there must come a point when the extraction of a phonological code will be impeded by the visual quality of the letter string. What is

needed, therefore, is some a priori basis for assuming that the phonological route will be less disrupted by degradation than the visual route. Until such evidence is forthcoming, evidence from the degradation paradigm must remain equivocal.

A second paradigm used by Stanovich and Bauer (1978) is the "response deadline" technique. In this study, subjects made lexical decisions to regular and exception words under speeded conditions. The result of this procedure was to significantly increase subjects' lexical decision speed and increase errors. The results showed that lexical decision times and error rates were virtually identical for regular and exception words. While acknowledging that it is somewhat undesirable to draw strong conclusions from acceptance of the null hypothesis, Stanovich and Bauer argue that such data are consistent with a postlexical interpretation of phonological recoding effects. They suggest that the speeded instruction leads to an abandonment of the cautionary phonological recheck and total reliance on the visual route.

Unfortunately, these data are equivocal in their interpretation. One cannot conclude that the absence of a regular word advantage under speeded-response conditions necessarily demonstrates that the effects of spelling-to-sound regularity arise through the application of a rechecking strategy that occurs subsequent to lexical access via the visual route. Instead, one could suggest that the phonological recoding effects obtained by Stanovich and Bauer (1978) arose through some prelexical involvement from phonological recoding, which, being an optional or relatively slower process, led to its effects' being eliminated when processing time was substantially speeded up. Thus, lexical decision might involve prelexical phonological mediation under normal response conditions but only visually based access under the speeded criterion.

Despite these difficulties in interpretation, the response deadline data of Bauer and Stanovich (1980) remain an empirical fact. It seemed reasonable, therefore, to examine how the observed difference in lexical decision speed for OPD and R words was affected by instructions to respond as quickly as possible. Clearly, if the effects obtained in the earlier experiments were to disappear just by instructing subjects to respond faster, then this would indicate that the phonological recoding strategy underlying these effects, whether post- or prelexical, is one that can be abandoned relatively easily, thus making its relevance to the process of normal reading considerably weaker. Accordingly, Experiment 4 examined the difference in lexical decision time for OPD and R words under cautionary and speeded-response instructions.

EXPERIMENT 4

Method

Subjects. The subjects were 18 students from Goldsmith's

College. None had taken part in any of the previous experiments.

Materials. Thirty OPD and 30 R words were selected with the same constraints as in the earlier experiments. These stimuli are shown in Appendix C.

Procedure. The general procedure was the same as that in the previous experiments. The only major departure was that the stimuli were presented by means of a tachistoscope that increased the visual angle to 3 deg. Subjects in the caution condition received the same instructions as had subjects in Experiments 1 and 2. Subjects in the speed condition were given basic lexical decision instructions but were told to make their decision "before the letter string disappears . . . or as soon as possible after that." They were further told that such a strategy would lead them to make errors but that this did not matter at all, since one of the aims of the experiment was to investigate the types of errors that people made when responding under speeded conditions. To facilitate fast responding, subjects in the speed condition saw each letter string for only 600 msec, whereas those in the caution condition saw each string for 1.6 sec.

Results

Subjects' correct mean response latencies in each of the four experimental conditions were calculated, and these data, along with the mean error data, are shown in Table 1. The data were analyzed in a manner similar to previous experiments and revealed a main effect of decision instruction [$\min F(1,22) = 18.6$, $p < .001$] that indicated that lexical decisions were made significantly faster in the speed condition. There was also a main effect of word type, which again showed that OPD words took longer to identify than R words [$\min F(1,72) = 15.92$, $p < .001$]. The interaction between decision instruction and word type did not approach significance in either the word- or subject-based analyses.

The error data were analyzed in a 2 by 2 analysis of variance. This revealed that more errors were made to OPD words [$F(1,16) = 7.61$, $p < .05$] and that more errors were made under speeded instructions [$F(1,16) = 4.96$, $p < .05$].

Discussion

The results from Experiment 4 showed that instructions to speed up responding led to much faster decision times for both OPD and R words and, in line with previous findings, OPD words took longer to identify than R words. The important finding, however, was that the

effect of word type did not interact with the type of response instruction (i.e., there was no difference in the size of the OPD-R difference in the two instruction conditions). These data show, therefore, that the phonological recoding effects obtained in the earlier experiments do not disappear when subjects are required to respond much faster than normal, a finding contrary to that obtained by Stanovich and Bauer (1978). In contrast to the conclusion of Stanovich and Bauer, these data suggest that the phonological recoding process underlying the observed differences between OPD and R words is one that is essential to the process of lexical access, inasmuch as instructions to respond faster do not reduce or eliminate its influence.

This conclusion is also supported by the error data, which showed that the significant difference in errors made on OPD and R trials was invariant across the two types of decision instruction. In addition, it should be noted that the error rate in the speeded condition, although significantly higher, is surprisingly low given the substantive increase in response speed. This suggests that subjects left to their own devices in a lexical decision task may well undertake a large amount of additional processing without much increase in performance.

CONCLUSION AND GENERAL DISCUSSION

The major findings of the current experiments can be summarized as follows. (1) Lexical decisions to words with exceptional spelling-to-sound correspondences are significantly slower than those to matched regular words, providing that the exceptional words have their pronunciation listed in the dictionary. A similar finding emerges when pronunciation latency is the dependent measure. (2) Exception words that do not have their pronunciation listed in the dictionary produce lexical decision and pronunciation times similar to those of matched regular words. (3) The processing advantage for R words over OPD words is neither removed nor attenuated by instructions to respond as quickly as possible.

The results of the current study thus demonstrate that some form of phonological recoding process does take place during lexical decision. Furthermore, it has been concluded that these effects emerge due to the operation of a nonlexical set of recoding rules, rather than from the properties of phonemic descriptions derived from lexical representations. Having established this, one must attempt to describe more precisely the actual involvement of phonological recoding in lexical access. It is possible, as Stanovich and Bauer (1978) suggest, that access may initially occur via the visual route but, because of task demands (e.g., the need to respond accurately), the "yes" response is held until a more slowly developing phonological code is made available (cf. Coltheart, Davelaar, Jonasson, & Besner, 1977) and matched with the phonemic code present in the activated lexical entry. Unfortunately, the current

Table 1
Mean Lexical Decision Times (T) in Milliseconds (Experiment 4)
as a Function of Word Type and Decision Instruction

Word Type	Speed		Caution		Mean	
	T	E	T	E	T	E
R	511	1.56	653	.57	582	1.06
OPD	562	3.33	733	1.78	648	2.06
Mean	537	2.46	693	1.18		

Note—E = mean number of errors (maximum = 30 in all cases). R = words with regular spelling-to-sound correspondence; OPD = words with pronunciation guide in the dictionary.

data provide no basis for distinguishing between this account of phonological involvement and one in which the recoding system forms an essential component of the lexical access code, since both would predict similar outcomes. Although one could argue, somewhat tentatively, that the persistence of the effects under speeded-response instructions supports the latter proposal, more direct evidence is needed if a firm conclusion is to be reached. One line of experimentation that would be particularly relevant to this issue would be to examine how the OPD-R difference behaves under conditions that strongly disfavor the use of phonological recoding, such as the use of pseudohomophone nonwords in a lexical decision task (Davelaar, Coltheart, Jonasson, & Besner, 1978). If the present effect remains robust under conditions such as these, then this would indicate a fundamental involvement of phonological recoding in lexical access. If it were to disappear, however, then one would argue that recoding represents only an optional component of the access process that can be dispensed with under certain conditions.

The second question of this study is that the phonological recoding process underlying the observed effects is not adequately described by the Venezky (1970) GPC rules, since possession of a minor GPC per se does not provide a sufficient condition for phonological recoding effects (Experiment 2). Instead, it appears that the system is more flexible, in that it can take account of some minor correspondences, but not others.

These results lead to the conclusion that Coltheart et al. (1979) failed to obtain a regularity effect because of the method by which they defined irregularity. A problem, however, is the data from Bauer and Stanovich (1980) and Stanovich and Bauer (1978). For these two studies, Stanovich and Bauer drew their samples of exception words mainly from the original Baron and Strawson (1976) sample, which, as noted in the introduction, contained only about 10% of words with dictionary-listed pronunciations. However, if one examines the only experiment for which individual item means are provided (Bauer & Stanovich, 1980, Experiment 4), it becomes clear that Bauer and Stanovich's inclusion of 29 OPD words in their sample of exceptions probably underlies their reported regularity effects.⁵ Table 2 shows the data from Bauer and Stanovich's Experiment 4, reanalyzed in terms of the MC, R, OPD distinction. It can be seen that, in both normal and degraded conditions, the mean reaction time to OPD words is much larger than that to MC words. Furthermore, mean reaction times to MC words do not differ, overall, from those to R words.⁶ These results thus lend support to the idea that only certain types of exceptions give rise to regularity effects.

In the light of the current findings, it is thus necessary to revise our ideas about how the phonological recoding process might operate and suggest new rules by which graphemic patterns might be assigned their

Table 2
Mean Lexical Decision Times (in Milliseconds) From Bauer and Stanovich's (1980) Experiment 4, Reanalyzed in Terms of the OPD, MC, and R Distinction

Word Type	Presentation			
	Normal		Degraded	
	Set A	Set B	Set A	Set B
OPD	870	841	841	1020
R	670	653	658	764
MC	640	653	660	766

Note—R = words with regular spelling-to-sound correspondence; OPD = words with pronunciation guide in the dictionary; MC = words with a minor spelling-to-sound correspondence but without a pronunciation guide in the dictionary.

correct phonological description. As a starting point, it is useful to look at the types of words that fall into the MC category (i.e., possession of a minor correspondence but no pronunciation listing). An examination of these words shows that many of them are, in fact, regular when larger graphemic units are considered. In Venezky's (1970) study, the maximum unit considered is two letters. However, it is entirely plausible that correspondence rules might extend beyond this to include larger units composed of three or even four letters. Consider the EA digraph, whose major correspondence is [i]. Under certain circumstances, it can be shown that there is a systematic deviation from the major correspondence dependent on the particular consonant following the EA digraph. In the case of EA followed by D, the major correspondence for EA is [e] (e.g., HEAD, TREAD, READY, BREAD), whereas the [i] correspondence occurs in only a few words (e.g., BEAD, MEAD). Other examples of minor correspondences' being regular in this manner include [U] in OOK, [ai] in IGN (final syllable), and the silent L in ALM. On the basis of this argument, words such as BREAD, BOOK, SIGN, and CALM could therefore be regarded as regular.

Another important influence on phonological recoding may be the relative frequency of words containing the minor correspondence compared with those containing the major correspondence. In the Venezky (1970) study, major and minor correspondences are determined solely in terms of the number of words possessing each of the possible correspondences; no account is taken of the actual word frequency of word groups representing these different patterns of correspondence. It is possible, however, that words containing the minor correspondence may occur more frequently than those containing the major correspondence and, as a result, make the minor correspondence the rule rather than the exception. This point is illustrated by the patterns of correspondence to the final letter unit OO-D. Table 3 lists the words that obey each of the three possible correspondences to OO along with each word's Kučera and Francis (1967) frequency value (scores are weighted to

Table 3
Distribution of Words Containing the Final Letter Unit OO-D as a Function of Its Three Possible Phonemic Correspondences

Major [u]		Minor [U]		Minor [ə]	
Word	KF	Word	KF	Word	KF
BROOD	9	GOOD	907	BLOOD	151
FOOD	247	HOOD	120	FLOOD	12
MOOD	37	STOOD	266		
ROOD	0	WOOD	100		
SNOOD	0				

Note—KF = Kučera and Francis (1967) frequency value, including the number of occurrences of each item in inflected form and as a suffix. The Oxford Paperback Dictionary (1979) served as the corpus.

include inflectives, e.g., FOODS, BLOODS, and suffixes, e.g., FALSEHOOD, UNDERSTOOD, but words containing OOD in some other form are not included). A simple count reveals that the major correspondence has more exemplars than either of the minor correspondences. However, if one examines the relative frequencies of the words containing each of the correspondences, it is clear that the minor correspondence [U] is the one that is most likely to be encountered, since its exemplars are much more common in the language. As a result, the phonological recoding system might operate some form of experiential bias, in that the minor correspondence may be assigned in preference to the major correspondence. Such a proposal may also explain why unique but relatively frequent exception words, such as PINT, COME, ONCE, WHOM, SUGAR, and SURE, are so easily identified, since our frequent experience of words such as these may lead us to become specifically aware of their unusual phonologies.

The need to specify a phonological recoding system utilizing rules about higher order orthographic units has also been suggested by a recent study of acquired dyslexia. Shallice, Warrington, and McCarthy (Note 1) report a patient, H.T.R., who was admitted to a neurological unit suffering from a progressive dementing disease. One of the major characteristics of her disease was a syndrome described by Shallice et al. as "semantic dyslexia," a disability in which it is assumed that lexical access depends entirely on phonological recoding, with access via the direct visual route completely impaired. A diagnostic feature of this syndrome is a marked inability to correctly pronounce words with irregular spelling-to-sound correspondence, the tendency being to regularize them (e.g., COLONEL is pronounced "col-o-nel").

In the study, H.T.R. was given a variety of reading tests, including one in which her ability to read words of different degrees of irregularity was investigated. It was found that her ability to read "irregular" words (e.g., SMOULDER) was significantly better than her performance on "very irregular" words (e.g., COLONEL). Shallice et al. (Note 1) noted that such data were incon-

sistent with a simple GPC-based recoding system of the type proposed by Coltheart (1978) and suggested instead that the patient's reading deficit might be explicable in terms of a phonological recoding system utilizing higher level units, such as vowel-plus-consonant clusters. To investigate this possibility, the patient was presented two types of irregular words: "typically divergent," in which all the items were irregular in terms of the Venezky (1970) rules but regular when higher order letter units were considered (e.g., HEAD), and "atypically divergent," in which all the items were irregular in terms of a higher level letter unit as well (e.g., BOWL). The results showed unequivocally that the patient performed much better on typically divergent words than atypically divergent words.

On the basis of these data, Shallice et al. (Note 1) conclude that H.T.R. has a preserved ability to use spelling-to-sound correspondence rules but, more important, that these rules operate on units larger than graphemes, including vowel-consonant clusters, subsyllabic units, syllables, and morphemes. As a result, the patient is able to cope with some irregular words, such as those classified as typically divergent, since these correspond to some higher order rule within the phonological recoding system.

This proposal, like that of the present author, thus suggests that the phonological recoding system underlying the identification of single words is one that can take account of higher order letter units. Given this, why is it the case that these rules fail for some words, resulting in delayed processing or complete misidentification, since one could presumably produce higher order units to cope with even the most unusual of correspondences? Again, the insight provided by Shallice et al.'s (Note 1) patient may provide useful clues as to the nature of this limitation in the normal reading process. On the basis of their observations, Shallice et al. conclude that H.T.R.'s failure on some irregular words arises because the correspondences pertaining to those words are more vulnerable for one of several possible reasons, including frequency of usage, age of acquisition, and the particular level at which a set of possible correspondences need to be differentiated. It is, therefore, interesting to speculate that these factors may also account for the delayed and incorrect processing of irregular words by normal subjects. Thus, the reading of H.T.R. may not be a total abnormality, but an extreme expression of factors that also influence the ability of normal subjects to read isolated words.

In conclusion, the current study suggests that some form of phonological recoding process is involved in lexical access. It appears that this system is more flexible than was initially thought and can take account of information beyond that represented by GPC rules. The above discussion has provided some indication as to what these additional sources of information might be, but this is far from exhaustive. What is needed is a closer and more

systematic examination of spelling-to-sound rules. The reliance on a dictionary to provide indications as to what these rules might be is a useful first step in approaching the problem, but more precise methods are needed if they are to be described properly. In addition, work in this area should make use of the potentially valuable contribution from studies of acquired dyslexia.

REFERENCE NOTE

1. Shallice, T., Warrington, E. K., & McCarthy, R. *Reading without semantics*. Paper presented to the Experimental Psychology Society, Birkbeck College, University of London, January 1981.

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NOTES

1. The theoretical basis of this prediction does, however, require further discussion. Coltheart et al. (1979) assert that lexical access based on GPC procedures would disadvantage exception words, since such a system would never provide their correct phonemic description—the assumption being that the system would only assign major correspondences. As a result, exception words, unlike regular words, can attain lexical access only via the visual route, whereas regular words can gain access by both routes. It is not clear, however, why this situation should actually produce longer lexical decision times for exception words, since it is the general position of Coltheart et al. that access via the visual route is actually faster (Coltheart, Davelaar, Jonasson, & Besner, 1977). Thus the fact that exception words would be wrongly phonologically recoded should be inconsequential to lexical access and resultant lexical decision. To predict faster decisions for regular words, it is therefore necessary to assume that phonologically mediated access could occur at a rate comparable to visual analysis or, alternatively, to suggest that lexical access in the lexical decision task requires the utilization of phonological as well as, or instead of, visually mediated codes.

A second problem concerns the exact manner in which the GPC system operates. One possibility is that the system might act in a probabilistic manner, assigning the major phonemic correspondence prior to any minor correspondence. As a result, exception words would receive the incorrect phonemic description (e.g., the EA in STEAK would be assigned [i], which would, in turn, fail to match any phonological description in the mental lexicon). This would lead to either increased decision time while minor correspondences were assigned or rejection of the letter string as a real word.

However, Coltheart et al. (1979) reject this possibility on the grounds that GPC rules applied to exception words often yield phonemic descriptions appropriate to other words, and thus GAUGE recoded in terms of the major correspondence for AU would produce GORGE. How, Coltheart et al. argue, could the system detect that ostensibly the same phonemic description is wrong in the first case, and thus initiate the assignment of minor correspondences, but in the latter case accept that it matches a lexical entry? Instead, as noted above, Coltheart et al. suggest that GPC recoding rules can be applied only to regular words. There is, however, a problem with this argument, since it presupposes that the GPC rules can discriminate between regular and exception words such that the latter do not become recoded. This is clearly not the case, since there is no indication that exception words have some additional, nonlexical feature that allows them to be discriminated. How, then, could this putative recoding system ignore exceptions?

Aside from the above difficulty, Coltheart et al.'s (1979) argument against a priority-based recoding system is notable because it assumes that lexical access via phonological recoding occurs in the absence of any visual information. Thus, the incorrect assignment of GORGE to GAUGE remains undetected because no information about the graphemic source of this phonemic description is still available. However, if reading were a process conducted without reference to visual information, then English, with its large numbers of homophones, would be impossible to read. Similarly, we would be unable to detect misspellings that preserve correct phonology (e.g., BRANE). In the light of these logical considerations, one must therefore conclude that any phonological recoding system would work in cooperation with the products of visual analysis. As a result, a priority-based system could work, since incorrect phonemic descriptions stemming from the allocations of major correspon-

dences to exception words would be detected because of a mismatch at the graphemic level (i.e., the system would be aware that it was a valid phonemic description derived from the wrong graphemic pattern) and a subsequent allocation of minor correspondences would be initiated. This proposal, however, begs a very important question. It seems obvious that, if visual information is retained during access, then the operation of phonological recoding seems superfluous unless one can argue that access in the presence of such a code is more efficient than in the presence of visually derived information alone.

To conclude, my position is that the demonstration of longer lexical decision times to words with irregular spelling-to-sound correspondences indicates the existence of a phonological recoding system that operates on all words. In addition, it is further asserted that the operation of such a system must, of necessity, be assisted by the presence of visual information.

2. The experimental and theoretical work reported in this paper was carried out prior to the publication of Bauer and Stanovich (1980). In consequence, I was unaware of the personal communication of J. Baron to these investigators.

3. At the request of the reviewers, the number of word meanings associated with each R and OPD word was calculated to check that the number-of-meanings factor had not been confounded with the R-OPD manipulation. For Experiment 1, the mean number of meanings associated with R words was 2.4 and with OPD words, 2.1. In Experiment 2, the figures were MC-2.8, R-3.2, and OPD-2.5, and for Experiment 4, R-2.8 and OPD-2.4. The *Oxford Paperback Dictionary* (1979) was used as the corpus. Comparisons of these mean values did not approach significance in any case.

4. The inconsistent words present in the Bauer and Stanovich (1980) regular word sample are ADVICE, ALONE, COUCH, DEW, DIVINE, FANCY, FOUL, FUSE, GOES, GROW, HOLY, HONEY, HOST, SOUR, TOLL, TONE, and TREAT (Set A), ALIVE, BEAT, BULLET, CROSS, LONE, NATION, RANGE, and TROUBLE (Set B). The consistent words in the irregular sample are ALIGN, CALM, CHASM, FIGHT, GNAW, GUESS, KNOB, METAL, THUMB, FAMOUS, and ISLAND. The basis by which consistency-inconsistency has been established is by using the criterion that "in general ends of words tend to be the most important units (e.g. rhymes)" (Bauer & Stanovich, 1980, p. 425). It should be noted that acceptance of this definition is the basis by which some exception words can be considered

as consistent. CALM, for example, is consistent with its visually similar neighbors PALM and BALM. The above sample also includes two-syllable words. Bauer and Stanovich explicitly avoid considering the consistency of multisyllabic words on the grounds that it is difficult to assign the relative salience of the constituent syllables. However, given the assumption that the ending of a word will always be an important characteristic of its rhyming qualities, the extension of the consistency notion to bisyllabic words does not seem too unreasonable. Certainly, it seems fair to assume that DIVINE will activate its inconsistent neighbor RAVINE; ADVICE, POLICE; BULLET, GULLET; and so on.

In this connection, it is also worth noting that the results of Experiment 3 do not support Glushko's (1979) finding that inconsistent words take longer to pronounce than consistent words. The MC group is composed of items that can all be considered inconsistent in some way (accepting, of course, that two-syllable words can be classified in this manner). The R words, however, contain only a few words that can be classified as inconsistent, and yet the list reading times for these items do not differ significantly from the MC lists. This suggests that Glushko's original pronunciation latency data might in some way be due to the unwitting inclusion of OPD words in his inconsistent sample. However, analysis of Glushko's materials indicates that this is not the case. Alternatively, one might argue that Glushko's consistency variable is evident only in the processing of monosyllabic words.

5. OPD words from the Bauer and Stanovich (1980) sample are ALIGN, AISLE, CAFE, CHAOS, CHASM, CHASSIS, CLICHE, ELITE, HEIR, LIQUOR, MARINE, PLAGUE, and SWORD (Word Set A), ACRE, ALLEGE, BALLET, CELLO, COLONEL, DOCTRINE, FACADE, GARAGE, GROSS, ISLAND, LAWYER, MASSAGE, MORALE, RAVINE, REGIME, ROUTINE, and SENATE (Word Set B).

6. In reanalyzing these data, it would have been more appropriate to compare each of the OPD and MC words with an R word matched for frequency and other factors, since an overall difference in word frequency between the OPD and MC groups probably accounts for some of the observed difference in reaction time. However, unlike the present study and that of Coltheart et al. (1979), experimental word groups appear to have been matched on overall frequency measure rather than on an item-by-item basis, thus making such a reanalysis impossible.

Appendix A
Materials and Individual Word Means (in Milliseconds) From Experiment 1

R Word	Mean	OPD Word	Mean	R Word	Mean	OPD Word	Mean
COMET	700	BERET	753	GRILL	757	GAUGE	937
BUMPER	750	BROOCH	848	CROSS	642	GROSS	991
IMBIBE	883	INDICT	819	OXYGEN	708	LIQUOR	711
SHACK	672	PLAIT	970	BLADE	656	DOUGH	653
CONSPIRE	725	CONJURE	925	SNAIL	754	SUEDE	756
CHIME	771	CHUTE	956	LIGAMENT	998	MERINGUE	1014
BRASH	858	MAUVE	818	MAGNET	656	MILIEU	872
CLICK	676	CASTE	1022	GLOBE	641	ELITE	826
VERB	778	VASE	686	FARMER	650	REGIME	725
VANE	786	QUAY	611	THUG	690	TSAR	854
BLEAT	873	SHOVE	790	SIEGE	712	AISLE	935
SHAMPOO	683	SCOURGE	816	PRANK	702	MITRE	830
THICKET	792	WORSTED	1069	RABID	1121	SUAVE	728
WELD	740	WARP	724	ETHIC	714	WHARF	809
VOW	771	WAD	1163	TULIP	702	YACHT	612

Note—Each R item is opposite its matched OPD counterpart.

Appendix B
Materials and Individual Word Means (in Milliseconds) From Experiment 2

MC Word	Mean	R Word	Mean	OPD Word	Mean
CHOIR	678	SIEGE	794	AISLE	847
DOUBLE	633	BITTER	711	MARINE	693
SAUSAGE	682	THIMBLE	780	BISCUIT	646
BUGLE	793	CHIME	788	CHUTE	827
CANOE	667	GLOBE	711	SWORD	660
PRAYER	611	MOTIVE	665	REGIME	717
FLOOD	637	GRILL	709	GAUGE	836
LOSER	819	TUTOR	658	MITRE	814
ACHE	725	VERB	640	ACRE	654
AUNT	629	DRUG	674	CAFE	672
WALLOP	810	DANGLE	809	INDICT	753
STEADY	662	DIVINE	684	SUBTLE	764
STEAK	672	ORGAN	677	LEVER	738
LETTUCE	715	LOBSTER	652	BROOCH	766
BUSY	593	QUICK	582	GROSS	699
WOLF	681	SLOT	729	WHARF	795
POLICE	607	MARKET	609	ISLAND	674
CASTLE	623	TURRET	955	TROUGH	733
VEHICLE	688	MIXTURE	685	COLONEL	813
PINT	724	LIME	703	LITRE	767
SIGN	644	FILM	644	CORPS	767
DOVE	652	CASK	750	VASE	664
WAND	779	SHIN	696	QUAY	687
SPINACH	681	LIGAMENT	886	MERINGUE	790
BOUGH	801	SHACK	708	PLAIT	856
BREAD	620	MATCH	655	BREATH	648
POUR	719	WELD	750	WARP	734
GLOVE	670	SPADE	641	DEBRIS	841
TONGUE	664	PRINCE	643	LIQUOR	735
SWAN	616	BLADE	703	DOUGH	713
HOVER	729	GROWL	696	SHOVE	749
BOWL	672	PLUG	640	WARD	628
DISOWN	793	REGAIN	759	CONJURE	795

Note—Each item is opposite its matched counterparts.

Appendix C
Materials and Individual Word Means (in Milliseconds) From Experiment 4 as a Function of Experimental Instruction and Word Type

R Word	C	S	OPD Word	C	S	R Word	C	S	OPD Word	C	S
BLADE	623	522	WHARF	696	555	COMET	638	498	BERET	930	543
DIVINE	668	511	SUBTLE	699	550	SNAIL	619	464	DOUGH	608	568
ORGAN	550	474	LEVER	801	502	MARKET	621	442	ISLAND	523	462
CHIME	648	563	CHUTE	744	642	COWARD	595	483	DEBRIS	850	681
GRILL	652	475	GAUGE	846	614	SHIN	691	483	QUAY	673	551
LEMON	542	454	LITRE	681	520	MIXTURE	615	532	COLONEL	674	536
QUICK	572	483	GROSS	724	501	INSIST	730	563	INDICT	693	583
MOTIVE	588	461	REGIME	630	547	THICKET	679	522	WORSTED	751	792
THRONG	787	570	TROUGH	760	528	SABLE	691	566	MITRE	736	607
BITTER	545	453	MARINE	645	489	BRASH	722	539	MAUVE	744	698
SIEGE	604	519	AISLE	766	513	DRUG	617	496	CAFE	657	539
WELD	639	590	WARP	675	580	CONFIDE	712	462	CONJURE	845	582
VERB	567	495	VASE	665	529	PELVIS	673	521	BROOCH	702	522
VOW	765	651	WAD	904	571	SHACK	706	596	PLAIT	824	636
GROWL	628	498	SHOVE	690	472	PLUG	576	471	WARD	597	542

Note—Each R word is followed by its matched OPD counterpart. C = caution instructions; S = speed instructions.

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