3 The Role of Orthographic Regularity in Word Recognition

Richard L. Venezky
University of Delaware

Dominic W. Massaro
University of Wisconsin

From preclassical Greece to the present day, most literate people in the Western world have been introduced to reading through correspondences of letters and sounds. This approach to beginning reading, now called phonics, was at the core of the ABC method that dominated reading instruction in Europe and England until well into the nineteenth century and in the United States until the early twentieth century (Smith, N. B., 1934/1965). By this method, children learned first the letters with their names and sounds, then various pronounceable (and not so pronounceable) bigrams and trigrams, then simple words, phrases, and sentences. For example, in *The American Primer*, a popular introduction to spelling and reading in use at the beginning of the nineteenth century, children were cycled through items like *bu, bo, ob, ub, yb, ic, ec, uc, yc, kni, kno,* and *knu,* before encountering their first real words.

By the early 1900s, the ABC method had evolved in the United States into an approach similar to that found in modern phonics programs, with deliberate sequencing of letter-sound patterns, separation of pattern words and sight words, and sensible strategies for decoding. *The Beacon Phonetic Chart*, for example, which was copyrighted in 1912, suggests that letter sounds, not letter names, be taught and that blending be done by a process that seems to minimize memory load. There is, so far as we can determine, no major difference between the Beacon method and the more enlightened (and expensive) phonics program offered in the schools today.

The introduction to reading by means of letters and sounds has not been unchallenged, especially in this century. Both silent reading and the whole-word approach have had periods of sovereignty in the last 75 years, but phonics is the standard approach today and is even found in some language experience programs.

TRADITIONAL JUSTIFICATION FOR PHONICS IN BEGINNING READING

But why? Is there evidence to justify this emphasis, or have reading instructors for 2,500 years (or more) followed false gods, as a few still claim they do (Smith, F., 1971)? The standard justification is that decoding (i.e., attaching sounds to letters and then blending the sounds to make a word) serves a number of ends. First, it provides a certain degree of independence for beginning readers. It allows them to translate unfamiliar printed words into phonological forms that may be familiar in their listening lexicon. Without this ability, the child is dependent on a teacher or another reader to confirm word identifications. Completely predictable letter–sound associations are not essential for this process, because, with context as an aid, the child can approximate the correct pronunciation of a word and then adjust it to a phonologically similar word that fits the immediate syntactic and semantic context. This is, in fact, what many beginning readers appear to do when they decode in context.

Second, decoding ability provides an element of self-assurance. Rather than confronting an ever-expanding number of arbitrary associations between words and printed symbol strings, as in Chinese, the child sees a more manageable set of letter–sound associations that can be used to build a large number of words. In addition, successful decoding is, in the early stages of reading, both an attention-keeping and a motivating device.

Whether these justifications for phonics approaches are supported by anything more than appeals to reason is not our concern at present. We are willing to accept that they are plausible, and we believe that the ends are desirable. If, however, these were the only goals of letter–sound teaching, then the current practice of ending phonics instruction at the end of the third year of reading instruction would be justifiable and we would have little more to say about it. After all, the goal of beginning reading instruction is not letter–sound knowledge but rapid word recognition, probably the only major skill unique to reading. Therefore, if letter–sound associations are not used by adults in recognizing words—and we think that they are usually not—then the sooner they are phased out of instruction the better. However, we suggest that a letter–sound emphasis in early reading serves another goal and that validation of this hypothesis could lead to significant changes in both beginning and middle-grade reading instruction.

ORTHOGRAPHIC REGULARITY AND WORD RECOGNITION

The overlooked role letter–sound instruction plays in reading acquisition is in word recognition but not through the direct application of letter–sound associations. As we show shortly, there is a rapidly expanding literature that demonstrates a central role for orthographic regularity in word recognition. By orthographic regularity we mean those features of printed English words that reduce the uncertainty of what letters might be present. Our basic argument is roughly as follows:

1. Rapid word recognition, which is essential for competent reading—oral or silent—depends on internalized (i.e., automatic) strategies that use orthographic regularity.
2. Phonics instruction, because of its emphasis on regular letter–sound associations, draws attention to the orthographically regular features of printed English words. That is, the procedure for analyzing printed words into subunits of pronunciation facilitates acquisition of the patterns that are also orthographically regular.
3. Furthermore, the instructional practice of separating certain (but not all) irregular words, which are learned as wholes, from pattern words, which are learned by analysis–synthesis, helps the reader to avoid generalizing from orthographically irregular sequences.

If we can establish these claims, then certain implications for initial and intermediate reading instruction need to be considered. We delay discussion of these, however, until after we have discussed (1) what orthographic regularity is, (2) how it relates to what is typically taught in phonics instruction, and (3) the evidence for claiming that orthographic regularity is essential to rapid word recognition. Because our discussion of the relationship between orthographic regularity and word recognition is based on a model of the processes involved in word recognition, we describe the model in the next section.

A MODEL OF WORD RECOGNITION PROCESSES

For purposes of the present discussion, we concentrate on the recognition activities that occur during a single eye fixation in reading. The model for describing these activities or processes, however, is part of a more general information-processing model for language processing that has been developed and tested over the past few years (Massaro, 1975). Our concern in presenting this model here is not to justify it over other models of word recognition but to provide a framework within which our hypothesis about word recognition can be explained and tested.

The text in reading is a sequence of letters and spaces that conform to orthographic, syntactic, and semantic constraints defining the written language. The average English reader begins at the top left-hand corner of the page and reads each line from left to right. A reader's eye movements are not continuous but occur in a series of short jumps called *saccades*. The fixation time between eye movements is roughly ten times longer than the movement time itself. An average reading eye movement of from 1° to 2° requires from 20 to 30 msec, whereas fixation time averages 250 msec (Shebilske, 1975; Woodworth, 1938). Initial processing of the visual stimulus must occur during the fixation time between eye movements, because the intensity of the light pattern is too weak and the processing time is too short during the eye movement.

During the eye fixation, the light pattern of the letters is transduced by the visual receptors into a feature detection system that places a set of visual features in preperceptual visual storage (see Fig. 3.1). For purposes of later exposition, we call this initial process *detection*. We describe the features as visual because we assume that there is a direct relationship between the stimulus properties of the letters and the information in preperceptual storage. The passive transduction of feature detection contrasts with the active construction of the following processing stages. There is no exact one-to-one relationship between the input and output of the following processing stages because these later stages actively use information stored in long-term memory in the sequence of transformations.

Given the set of visual features in preperceptual visual storage, the primary recognition process attempts to synthesize these isolated features into a

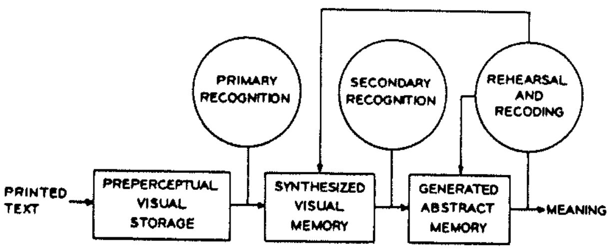

FIG. 3.1. Flow diagram of processing printed text.

sequence of letters and spaces in synthesized visual memory. To do this, the primary recognition process can use information held in long-term memory, which for the accomplished reader includes a list of features of each letter of the alphabet along with information about the orthographic structure of the language. The primary recognition process uses both visual features and the orthographic structure of the language in its synthesis of the letter strings.

Because there are a limited number of ways that sequences of letters and letter groups can be put together to form English words, the reader's knowledge of this regularity can help to resolve the letters in a string that conforms to the language (Massaro, 1975). This knowledge can also help the reader to resolve the relative spatial positions of the letters once they are recognized (Estes, Allmeyer, & Reder, 1976).

The primary recognition process operates on a number of letters simultaneously (in parallel). The visual features that are read out at each spatial location define a set of possible letters for that position. The recognition process chooses from this candidate set the letter alternative that has the best correspondence in terms of visual features. However, the selection of a "best" correspondence can be facilitated by knowledge of orthographic structure. The primary recognition process, therefore, attempts to use both the visual information in preperceptual storage and knowledge about the structure of legal letter strings. The interaction of these two sources of information is a critical issue in the analysis of word recognition. (We review the most recent literature on the role of orthographic structure in letter and word recognition in a later section of this chapter.)

The primary recognition process transmits a sequence of recognized letters to synthesized visual memory. Figure 3.1 shows that the secondary recognition process transforms this synthesized visual percept into a meaningful form in generated abstract memory. We assume that synthesized visual memory holds a sequence of letters that is operated on by the secondary recognition process that tries to identify a meaningful word. The secondary recognition process makes this transformation by finding the best match between the letter string and a word in the long-term lexicon. Each word in the lexicon contains both perceptual and conceptual codes. The concept recognized is the one whose perceptual code gives the best match and the one most likely to occur in that particular context.

The structure-generated abstract memory corresponds to the short-term or working memory of most information-processing models. Recoding and rehearsal processes build and maintain semantic and syntactic structures at the level of generated abstract memory.

In this model, the role of orthographic structure in word recognition is concentrated in the primary recognition process, and orthographic structure serves to facilitate both the recognition of individual letters and the resolution of relative spatial positions. The use of orthographic structure for letter resolution can be viewed in the following manner:

> For letter strings that are not spelled like English words, orthographic structure probably plays no role. Letters are resolved individually, solely on the basis of their visual features, which are carefully evaluated during the primary recognition process. For letter strings that are spelled like words, however, less visual information needs to be processed than in the nonword case because the constraints of English orthography aid the reader in deciding what might be present. If visual information were to arrive over time, with the gross features available before the detailed features (Massaro & Schmuller, 1975), then the reader would be able, by successive sampling, to terminate visual processing when sufficient information is available for each letter decision. If, for example, an initial *th-* has been resolved in a letter string and the features available for the next letter match either *c* or *e*, the reader might accept *e* without waiting for further visual information, because initial *thc-* is irregular whereas initial *the-* is not.[1]

To test the validity of this model, we must first define orthographic regularity.

DEFINING ORTHOGRAPHIC REGULARITY

A page of printed English looks quite different from a page of printed Hebrew or a page of printed Finnish, even to a person who understands none of these languages. English and Hebrew have no overlap in symbol repertoires, whereas English and Finnish have a large, but not 100%, overlap. (Finnish uses the letters *c, f, q, w, x,* and *z* only in a small number of loan words, and English has no equivalent for Finnish *ä* and *ö*.) Experienced readers of Hebrew texts expect Hebrew letters, readers of Finnish texts expect Finnish letters, and readers of English texts expect English letters.

We presume that, in addition to these differences in symbol repertoires, readers are aware of other characteristics of their written language. Table 1 shows several sentences from Finnish and English first-grade readers in which all nonblanks have been replaced by *X*'s. Because of the difference between average word length in Finnish and English, the identification of the English sample should be obvious. How refined this sense of average length is has not been explored so far as we know. Could an English reader, for example,

[1]We have greatly simplified the recognition processes in this description, leaving out for purposes of explication the complexities of what are probably asynchronous, partially overlapping processes. More detailed explanations of these can be found in Turvey (1973) and Massaro (1975).

TABLE 3.1
Differences Between Average Word Length in Finnish and English

Sample A	*Sample B*
XXXXX XX XXXXXXXXXX XXXXXXXX.	XXX XXXX XX XX XXX XXXX.
XX XX XXXX XXXXXXX XXXXXXXX,	XXX XXXXX XXX XXXXXXXX XXX
XXXXX XXXXX XX XXXXXX XXXXXX	XXX.
XXXX.	XXX XXX XXXXXXX XXXX XXXXX
XXXXX XXXXX XXXXXXXXXXX XXXXXXXX.	XXXX XXXX XXXX XXXXXX
	XXXX.

distinguish English from French and German samples composed as in Table 3.1?

A third language-dependent feature of texts is the distribution of word lengths that normally occur in any text. All natural languages have evolved lexicons that contain two groups of words: a relatively small, closed set of function words, which serve primarily (but not entirely) to signal word relationships (i.e., syntax), and an open-ended set of context words that serve primarily to signal meanings (Hockett, 1958). The function words are heavily used, tend to change relatively slowly over time, and tend to be (according to Zipf, 1935) relatively short in phonological and, therefore, alphabetic length. The content words, in contrast, have a wide distribution of frequency of occurrence, change more rapidly over time than the function words, and vary from short to quite long. Real texts are characterized by distinctive distributions of word lengths, depending on the manner in which function words are realized in print. In Hebrew, for example, the definite article, the coordinating conjunction "and," and most prepositions are prefixed to content words, thus reducing the number of short, printed words relative to most European languages.

But the most important characteristics of orthographic regularity for studying word recognition are not those that characterize sequences of words but those that define the allowable patterns of letters within single words. Two entirely different approaches have been taken in describing this regularity. The first method, described as *probabilistic*, uses word tokens sampled from real texts to define probabilities of occurrence for single letters, bigrams, trigrams, and so on. From these data, various types of approximations to English words are generated. For example, Hirata and Bryden (1971) generated tables of zero- to fourth-order approximations to English that have been used in studies of orthographic regularity by, among others, Lefton and Spragins (1974) and Lefton, Spragins, and Byrnes (1973). Mason (1975), on the other hand, generated pseudowords from the single-letter frequency counts published by Mayzner and Tresselt (1965). These differed from the Hirata and Bryden (1971) data in that letter position and word length were considered by the former, but not the latter.

The second method, called *rule-governed*, is based on studies of the English orthography (e.g., Hockett, 1963; Venezky, 1967, 1970). Rules define which letters or letter sequences are allowed (or not allowed) in which positions or graphemic contexts. Although no comprehensive set of such rules exists, reasonable approximations to rules can be drawn from Venezky (1967, 1970). This approach to defining orthographic regularity has been used extensively by Gibson and her colleagues (e.g., Gibson, Osser, & Pick, 1963) and by many others (e.g., Baron, 1977; Thomas, 1968) in studies of word recognition.

Since both methods for defining orthographic regularity are commonly used in experimental studies, and since each implies a different approach to instruction, we consider them in detail.

Probabilistic Approaches

The earliest approach to generating English pseudowords was suggested by Shannon (1948) and used by Miller, Bruner, and Postman (1954) and by Wallach (1963) in studies of word recall. A zero-order approximation to English was generated by selecting each letter for a string randomly, giving equal weight to each letter. A first-order approximation resulted from the same procedure but with the letters weighted by their frequency of occurrence in English texts. For higher orders, an ith-order approximation was generated by selecting an initial string of length $i - 1$. Then a sample text was scanned linearly for that string. Once the string was found, the next letter in sequence was added to the string, the first letter was removed, and the process was repeated until a desired number of letters (including the initial $i - 1$) were selected.

This scheme tends to generate highly regular pseudowords at the higher order approximations, especially if the last letter drawn for each word is always selected from the last position in an English word.[2] Miller et al. (1954) used this restriction in generating eight-letter words that were fourth-order approximations to English (e.g., *mossiant, oneticul, preveral, favorial, aphyster*). Wallach (1963), however, employed six-letter pseudowords by truncating those published by Miller et al., thus occasionally risking non-English endings (e.g., *mossia, onetic, everal, iorial, aphyst*).

Shannon (1951) also suggested a parlor game technique for generating pseudowords. The first person constructed a word by adding letters to an initial string. The first letter added was retained, the first letter of the starting string was dropped, and the process was repeated with another person. Although Shannon assumed that letter frequencies in the resulting strings would approximate those of English texts, Attneave (1953) showed that college students often misjudge the relative frequencies of individual letters.

In contrast to these sequential dependency schemes are the correlational approaches that use letter and letter-string frequency tables to produce pseudowords with controlled bigram and trigram counts. Anisfeld (1964), for example, suggested that the Gibson, Pick, Osser, and Hammond (1962) results could be explained by differences in summed bigram frequencies based on the Underwood and Schulz (1960) tables. But a later study (Gibson, Shurcliff, & Yonas, 1970) showed that summed bigram and trigram frequencies were not good predictors of recognition scores on pronounceable and unpronounceable pseudowords.

Underwood and Schulz (1960) generated bigram and trigram frequencies from 2,080 words sampled from Thorndike and Lorge (1944) and weighted with respect to their frequency of occurrence. These counts are based on overall frequency of occurrence (tokens), rather than word types (the number of different words contributing to the sample), and summed over all occurring word lengths and serial positions. Failure to account for word length provides obvious problems in describing orthographic regularity. For example, the trigram *ght* occurs relatively often summed over all word lengths but does not occur in three- or four-letter words.

Summed bigram or trigram frequencies without regard for serial position are also inadequate for a description of orthographic regularity.[3] For example, the bigram *ck* is legal at the end but not at the beginning of a word. It is unlikely, however, that this difference can be accounted for in summed bigram frequencies, because *k* plus vowel is as likely as vowel plus *c*. This allows *ckad* to be as "legal" as *dack*. (Summed trigram frequencies can handle the positional contraints on *ck* quite well but cannot handle positional constraints on trigrams such as *dge* and *tch*.)

The objections to not including word length and serial position in assigning frequencies to bigrams can be overcome by using the Mayzner and Tresselt (1965) tables, which give bigram frequencies for each word position in words of from three to seven letters in length. However, both orthographically regular and orthographically irregular strings can be generated with either high or low bigram counts. Shown in Table 3.2 are two lists of words with their bigram counts. Notice that although the words in the first column are orthographically regular by the rules given in the next section of this chapter, they have extremely low bigram counts. Similarly, the irregular strings in the second column have relatively high bigram counts. Similar but less striking

[2] In the Shannon (1951) system, all 26 letters of the alphabet plus space were used, so positional constraints were guaranteed for second-order and higher approximations to English.

[3] Gibson and Levin (1975, pp. 207–211) distinguish between correlation approaches such as the Underwood and Schulz (1960) and the conditional redundancy approaches, which consider positional constraints. However, this dichotomy does not apply to the positional probability approach, which is discussed shortly.

TABLE 3.2
Bigram Counts for Orthographically Regular and Irregular Strings

Regular		Irregular	
bipon	17*	thrsm	417
slevs	21	thrse	565
slevy	30	sthse	341
eddop	2	eaich	297
edaby	0	whrst	378
dufip	0	hoier	407

Source. Based on Mayzner and Tresselt (1965).
*The count of 17 for *bipon*, for example, is the sum of the counts (for 5-letter words) for *bi* in positions 1 and 2, *ip* in positions 2 and 3, and so on.

demonstrations can be made of pseudowords generated by controlling trigram frequencies.

Letter and letter-string frequency tables have also been used to generate approximations to English without regard to summed bigram and trigram frequencies. Hirata and Bryden (1971), for example, generated ten-letter strings for orders of approximation to English from zero to four, using the Mayzner and Tresselt (1965) and Mayzner, Tresselt, and Wolin (1965a, 1965b) tables of single letter, bigram, trigram, and tetragram frequencies. The algorithms used for generating these strings did not use positional information; nevertheless, they guaranteed orthographic regularity for fourth-order strings, except for word endings and word beginnings. Lefton et al. (1973) and others have used these lists in developmental studies of guessing missing letters in pseudowords.

A totally different probabilistic approach is represented by Mason (1975), who used the Mayzner and Tresselt (1965) single-letter tables to generate words with high and low positional frequencies. A word has a high positional frequency count if the letters for that word are in positions in which they are frequently found in words of the same length in texts. Mason (1975) found that positional frequency was a good predictor of letter search speeds in pseudowords. However, her test items confound positional frequency and orthographic regularity, with the pseudowords high in positional frequency tending to be orthographically regular and those low in positional frequency irregular. For example, one of the highest possible positional frequency counts for a four-letter string occurs for *THET* (3,794); nearly as high is an orthographically irregular string, *THRT* (3,421); and an orthographically regular word *JUFF* has a count of only 371. Thus if orthographic regularity relates to recognition ease, positional frequency counts are inadequate for defining it. Since both regular and irregular pseudowords can be generated

with both high and low positional frequencies, the relative contributions of the two variables to Mason's task could be examined.

Rule-Governed Approaches

In contrast to probabilistic approaches, rule-governed approaches are based on generalizations about the underlying patterns of English orthography and, therefore, might generate some sequences that do not occur in real words and reject some that do. In addition, rule-governed approaches are based on word types, whereas probabilistic approaches are based on word tokens. In rule-governed approaches the actual frequency of occurrence of a word in texts is not considered. This bias appears to be one of convenience rather than overt decision, resulting from the use of word types in the major studies of English orthography. (Some attempts have been made to evaluate the relative contributions of word types and word tokens in the generalization of letter–sound patterns, but the results have been inconclusive (see Johnson, D. D., 1970; Johnson & Venezky, 1975).

Restrictions on letter sequences in English words derive from two primary sources: graphemic conventions and phonological constraints. The first source is a 1,400-year accumulation of scribal practices, printing conventions, lexicographers' selections, and occasional accidents that somehow became codified as part of the present orthographic system. The second source is the phonology of English, which by its own constraints on sound sequences places restrictions on letter patterns.

Graphemic Conventions. English graphemic conventions apply primarily to sequences of the same letter and to positions in which letters and letter sequences may occur within words. No letter can be tripled in an English word, and only 16 letters can be doubled (geminated). Those that cannot be doubled include *a, h, i, j, k, q, u, w, x* and *y*. Exceptions to this latter constraint are few (excluding proper nouns and recent borrowings), for example, *aardvark, skiing*, and *trekked*. The letter *v* rarely doubles, but several exceptions are well estabished in the language (e.g. *flivver, savvy, navvy*). Those letters that can double do so only in medial and final word positions. This pattern has fewer than a dozen exceptions (e.g., *llama, eel, oodles, ooze*), not counting technical terms beginning with the combining form *oo-*.

These patterns and their exceptions bring us to the question of how we establish a pattern or rule. Of the 100,000 or so word entries in common desk dictionaries, perhaps from 15 to 20 begin with geminated letters. Does 99.98% regularity establish a pattern? For the present, we will dodge this issue by claiming that the patterns of regularity presented here are only potential patterns suggested as a basis for psychological studies. Their derivation, however, is based entirely on either frequency or graphemic environment, without precise definition of what frequencies are rule-producing, except that types rather than tokens are counted.

A second constraint on doubled consonants is that they do not (with a few exceptions) occur after vowel digraphs. A pseudoword like *louff* would be irregular, or at least more irregular than words like *louf* and *luff*. The three geminate replacements *tch* (*chch*), *dg* (*gg* = /ǰ/), and *ck* (*cc* or *kk*) obey the same rules as geminates: They do not occur initially or after digraph vowels. Thus *tchan, dgerp, heeck,* and *lautch* are irregular.

Some single letters also have positional constraints in English words. The letter *q* must always be followed by *u; j, u,* and *v* do not occur in word final position: and *k* does not occur finally after a single-letter vowel. (A few exceptions exist for *u*, including *you* and *thou*, and there is one for *k*: *trek*.) By this restriction, pronounceable pseudowords such as *baj, blou, mek, and sliv* are irregular.

Further restrictions can be found for vowel sequences, especially digraph vowels ending in *i* and *y*, but these are less consistent than the constraints mentioned above.

Phonological Conventions. Because of a series of sound changes that began during the Old English period, most noun inflectional endings coalesced into what is presumed to have been an unstressed, neutral vowel (/ə/), which was spelled with the letter *e*. By the time this vowel became silent, other sound changes had lengthened the vowel in a preceding syllable, so that the final *e*, although unpronounced, became a marker for distinguishing vowel quantity. Thus the pairs *man–mane* and *bit–bite* arose. The consequence of these changes, plus other conventions such as the use of a suffix *s* for noun plural and third person singular in the present indicative forms of verbs, is a highly uneven distribution of letters in different word positions. This distribution is further augmented by the frequent use of common prefixes and suffixes as word-forming elements (e.g., *co-, pre-, -ing, -ed*). This feature, which is summarized by Mayzner and Tresselt (1965) for words with from three to seven letters, reflects both phonological and scribal variables.

A different set of constraints results from the restrictions of sound sequences in English. For example, certain consonant sequences do not occur in word initial position (e.g., *ds-*), and certain others do not occur in word final position (e.g., *-sd, -fd, -pg*). Notice also that although /wh-/ is an illegal phonological sequence for English, *wh-* is an orthographically regular spelling. The earlier spelling, *hw-* was reversed by eleventh- and twelfth-century scribes to minimize graphic confusions. Whorf (1956) attempted to summarize these constraints for English monosyllabic words.

Unpronounceable consonant sequences from other languages or from earlier periods in the history of English often retain their original spellings, even when the sound sequences are altered to conform to Modern English. Spellings such as *write, psychology, hymn,* and *lamb* are representative of this group. (However, some forms that appear to belong in this group result from scribal pedantry, e.g., *ptarmigan, thumb, crumb.*)

Other orthographic constraints based on phonological conventions could be listed, but they are of less importance than those already described. One implication of the constraints described above is that different degrees of regularity are possible. For example, *flab, kip,* and *petch* are pronounceable and orthographically regular; *cootch, lev,* and *goff* are pronounceable but (mildly) irregular; *ckab, baaaf,* and *lixx* are pronounceable (?) but more irregular; and, finally, *wksliy, tchfole, and xxx* are unpronounceable and highly irregular.

ORTHOGRAPHIC REGULARITY AND PHONICS INSTRUCTION

If the psychological reality of orthographic regularity is based on probabilistic information derived from token counts, then phonics instruction is only marginally helpful at best, for helping children internalize this structure. Because letter–sound associations presented in phonics programs are selected on the basis of word types and not word tokens, such programs could even have a negative influence by, for example, teaching certain high-frequency words that have irregular correspondences as sight words. Probabilistic information requires continual exposure to normal texts. The tightly controlled vocabularies of the primary readers and the emphasis in phonics instruction on regularly spelled words probably leads to probability generalizations that differ in some instances quite markedly from those published by Mayzner and Tresselt (1965) or Hirata and Bryden (1971).

If, however, the psychological reality of orthographic regularity derives from rule-governed information, then the relationship between some of the potential sources of rule-governed orthographic regularity summarized above and the patterns taught in phonics programs becomes important. The units typically stressed in phonics programs are the simple (i.e., single-letter) vowel patterns, the digraph vowels (*ee, ea, ow,* etc.), sequences such as *wh-, qu-, dge,* and *tch,* the common (and not so common) initial and final consonant clusters, and the common prefixes and suffixes—all of which play a role in rule-governed regularity. What are not introduced overtly are any of the patterns that require the absence of spelling (e.g., the nondoubling of *x*). Exactly how these patterns might be taught is not obvious however. Contrasting legal with illegal spellings might be counterproductive in that it would expose students to irregular strings which they might then incorrectly use in generalizations on regularity.

Equal in importance to which patterns are introduced is the manner of introduction, which depends (in the better programs) on inductive rather than deductive reasoning. A spelling such as *ee* is usually introduced alone (with its most common pronunciation) and then in a group of words divided by position. Thus *see, thee, free*, and *bee* might be grouped, then *seek, beet, seed*, and so on, with the *ee* emphasized by underlining or color.

A second presentation procedure that tends to emphasize orthographic regularity centers on what some phonics programs call phonograms—common vowel–consonant or consonant–vowel sequences that are productive for word building. Early in many programs the *-an* family is introduced: *fan, tan, man, van*, and so on. In addition to emphasizing particular letter–sound patterns, this practice induces a segmentation strategy that may transfer directly to word recognition.

Finally, the isolation of some irregular forms such as *debt, thou, is* and *was*, that are taught as sight words, probably reduces the opportunity for generalizing their spellings as regular. But notice that many other sight words, which are irregular from a letter–sound view (*what, wash*, and *from*), are not orthographically irregular. What effect this has on the reader's sense of orthographic regularity is not clear. The differences between orthographic regularity and letter–sound regularity should not be overlooked. Orthographically irregular strings such as *hek, ssilf*, and *lowtch* are pronounceable (and regularly so), whereas orthographically regular words such as *triple, colonel, eighth, business*, and *arced* have irregular letter–sound associations.

The point to be stressed here, however, is that a logical phonics program introduces almost all the orthographic patterns that can be exemplified positively and introduces them by procedures that give overt attention to the relevant spelling units for orthographic regularity.

WORD RECOGNITION

In this section we review a number of experiments that involve the recognition of letters, nonwords, and words and show the role orthographic regularity plays in the recognition processes.[4] By *recognition* we mean the resolution of the visual information in order to perform the experimental task. Since experimental tasks differ to the extent that they require different degrees of resolution on the part of the subject, the number of processes involved in recognition will vary accordingly. The nature of the task must be accounted for both in the analysis of the results and in the implications that are drawn for theory. It is somewhat disappointing that some researchers have failed to be concerned with the processes involved in tasks such as searching for a target letter in a letter string, reporting component letters, pronouncing a letter string, or determining whether a particular letter string is a word. The different levels of processing in these tasks are clarified somewhat by distinguishing between detection, primary recognition, and secondary recognition (shown in Fig. 3.1).

An example of a study that failed to account for the psychological processes in the task is that of N. F. Johnson (1975). In one of his experiments subjects were given a test word every 10 sec and asked to classify it as either the same as or different from a target word. For example, for the target word *block*, the subjects saw a list of five-letter words and had to classify each word as the same as or different from *block* by hitting one of two buttons. In the letter target condition, the subjects again saw a series of five-letter test words, but now they were asked to respond according to whether each test word contained a particular target letter. The reaction times were shorter for the target word than for the target letter condition, leading Johnson to conclude that words are identified as whole patterns, suppressing the identification of their component letters.

Johnson's results do not show that words are processed as whole patterns when the nature of the task is made apparent. Subjects in the word condition had to decide whether a five-letter string of letters was the same as a five-letter string of letters in memory. Subjects in the letter condition had to decide whether any of five letters in the string was the same as the target letter in memory. Accordingly, the critical difference between the two conditions is probably not in word versus letter targets but in having same-length or different-length target and test items. Because (in our model) letters in a sequence can be processed in parallel, subjects can make a relatively direct comparison between the target and test words in the target word condition. Subjects in the word condition could have adopted a very liberal criterion of sameness. Johnson chose his words randomly; thus, there was a low probability that a test word on different trials would have even one letter in the same position as a letter in the target word. If even one or two test letters had been the same as the corresponding target letters, the subject could have initiated a "same" response before the processing of the test item was complete. Similarly, a difference of one or two letters would have been sufficient to initiate a "different" response. In the target letter condition, however, the target letter had to be compared to each of the five letters in the test word. Therefore, each of the test letters had to be processed sufficiently to

[4] Orthographic regularity should not be confused, as it often is, with spelling-to-sound regularity. The latter means that there is a regular (i.e., predictable) association between the spelling of the language and the way it is pronounced. The more regular relationships between spelling and sound have led a number of researchers to postulate that reading a word involves first recoding it to speech at some level and then accessing meaning on the basis of this speech code (Gough, 1972). However, it is unlikely that the spelling-to-sound correspondences could facilitate visual processing because the letters would have to be recognized before their sounds would be available.

determine whether it was the same as or different from the target letter. Subjects in this condition could not terminate their processing until they found the target letter or determined that all the test letters were different from the target letter. The additional processing required in the target letter condition relative to that required in the target word condition can account for the longer reaction times in the target letter condition, even though letters were the unit of analysis in both conditions. Accordingly, Johnson's conclusion that a word is processed as whole, suppressing recognition of its component letters, is not warranted by his experimental results.

In contrast to Johnson's idea that processing a word conceals its component letters, a number of investigators have assumed that a target letter would be found more quickly in a word than in a random letter string. In general, it is assumed that the time to find a target letter should be an inverse function of the conformity of the letter string to the orthographic structure of the language. The implicit assumption in this research is that the visual resolution of a sequence of letters will occur faster when the letters conform to the orthography of the language than when they do not. Letter search is dependent on letter resolution and, therefore, should reflect the time it takes to resolve letter sequences. Subjects appear to be able to perform a Neisser (1964) search task for a given target letter more rapidly if they search through a list of words than if they search through a list of random strings (Krueger, 1970; Novik & Katz, 1971).

Mason (1975) used a target search task to study the contribution of one aspect of orthographic regularity. Good and poor sixth-grade readers searched through six-letter strings for the presence or absence of a target letter. Words and nonwords were used, and the nonwords differed in the degree of orthographic structure as defined by positional frequency. As we explained earlier, the positional frequency of a letter in a letter string is the frequency of occurrence of that letter in the same position in words of the same length sampled from common texts. Given this definition, a letter string can be given a summed positional frequency that represents the sum of the positional frequency of all the letters in the string. Mason tested the idea that search time for a letter should be an inverse function of the summed positional frequency of the letter string. The implicit model of the letter search task is that the subjects must first recognize the letters in a string and then compare these letters to the target letter. Differences in the search times for a given target letter in different letter strings should reflect differences in the time required to recognize the letters of the strings. Mason found that good readers were faster (on both "yes" and "no" trials) on strings with high positional frequencies than on strings with low positional frequencies. Poor readers showed no difference. The results support the idea that the time needed to resolve (recognize) the letters in a string is influenced by the likelihood of letters occurring in their most common positions.

Although summed positional frequency appears to account for the recognition times in Mason's study, we do not believe it is the critical variable that defines orthographic regularity. Consider some of the arrangements of the letters that make up the word *person*, which has a summed positional frequncy of 1,141, based on the Mayzner and Tresselt (1965) single-letter table. The string *pornes* contains the same letters in different positions and has a count of 1,858. The string *enspro* has a count of 383. Looking at these nonwords, we see that *pornes* is spelled like an English word and therefore should be relatively easy to recognize, whereas *enspro* violates what we know about English spelling and should therefore be relatively difficult to recognize. Table 3.3 lists some other letter strings used by Mason. The letters have been rearranged to yield strings with almost equal summed positional frequencies but with differing orthographic regularities. We are currently testing the prediction that the orthographic regularity as defined by graphemic rules and not as defined by the summed positional frequencies will influence recognition times when these variables are independently varied in a target search task.

There is a growing research literature that supports the idea that visual recognition of letter strings can be facilitated by orthographic regularity rather than by spelling-to-sound regularity or word meaning. Baron and Thurston (1973) found that visual recognition is as good for pseudowords that obey orthographic rules as it is for real words. Baron (1975) carried out a series of experiments showing that orthographic regularity, but not phonemic quality or meaningfulness, has an effect on visual information-processing tasks. The time taken to decide whether two strings of letters were visually identical was not longer when the strings were pseudowords instead of words, but it was longer when the strings violated orthographic regularity. Homophone word pairs did not require more time in this task than did nonhomophonic words. Meaningfulness did not facilitate search for a target letter in a letter string, although orthographic regularity decreased search time.

TABLE 3.3
Letter Strings of Similar Positional Frequency that Are Either Orthographically Regular or Irregular

Regular[a]		*Irregular*[a]	
girbed	(1,721)	grbied	(1,690)
pirons	(1,409)	sopinr	(1,409)
filtes	(1,750)	flties	(1,775)
citred	(1,861)	tcried	(1,886)
hougen	(1,399)	nhoueg	(1,409)

Note. Based on Mason (1975).
[a]The numbers in parentheses give the summed positional frequency for letter strings.

In contrast to Baron's (1975) and Baron and Thurston's (1973) findings, Manelis (1974) found significant differences between real words and pseudowords in a Reicher (1969) task. Overall, a letter in a word was reported about 5% more often than a letter in a pseudoword. However, that difference could have been due to differences in orthographic regularity, not wordness per se. Although Manelis found no effect of bigram and trigram frequency in a post hoc analysis, the analysis in our section on probabilistic approaches shows that these measures are not good indexes of regularity. It remains to be seen if our interpretation can account for the observed differences in the Manelis study.

We believe that there is substantial evidence to argue that word meaning does not influence the initial visual resolution of letter strings (Baron, 1975; Baron & Thurston, 1973; Massaro, 1975). One implication of this is that there is nothing visually unique about a sequence of letters that spell a word beyond that accounted for by orthographic regularity. The perceptual equivalence between words and pseudowords argues that words do not have supraletter features that allow the words to be recognized without resolution of at least some of the letters or letter features. Many teachers and psychologists believe that words can be recognized on the basis of overall shape or configuration without resolution of the component letters (Johnson, N. F., 1975; Miller, 1972). If words can be recognized as wholes, then orthographic regularity would play a very minor role, if any, in word recognition. If words are recognized on the basis of supraletter features, there would be no chance for orthographic regularity to help resolve the component letters.

However, there is now good evidence against the hypothesis that words can be recognized on the basis of supraletter features. The most straightforward analysis was performed by Groff (1975), who examined the shapes of high-frequency words taken from school books. The shape was defined by drawing a contour around the letters so that, for example, *elephant* would be $\boxed{\text{elephant}}$. Only 20% of the 283 words sampled were represented by a unique shape. The author rightly concluded that the small number of words that can be represented by a unique shape precludes the use of this cue for accurate word recognition.

There is also experimental evidence against the idea of word recognition based on supraletter features. Thompson and Massaro (1973) and Massaro (1973) found that a letter likely to be confused with another letter was just as likely to be confused in word presentations as in single-letter presentations. If recognition of words involved the use of features other than those contained in the component letters, there should have been different degrees of letter confusability in letter and word presentations.

McClelland (1976) presented four-letter words, pseudowords, or unrelated strings in either the same case or in mixed upper and lower case. (The letters alternated in case in the mixed case condition.) The results showed that the

recognition of a letter was equally disrupted by mixing the cases of letters in both words and pseudowords. Mixing letter cases did not disrupt recognition of letters in the unrelated letter strings. If readers used whole word shape or configuration cues in word recognition, mixing letter cases should have disrupted recognition of words more than of pseudowords. The results support the idea that legal spelling patterns are functional at an intermediate stage of visual recognition and that letters alternating in case can disrupt the resolution of these patterns. Given that the unrelated strings did not have legal spelling patterns, alternating letter case did not disrupt processing of the letters.

Baron (1976) asked observers to pronounce regular words and exception words. Regular words were defined as words that obey the rules of spelling-to-sound correspondence in English (see Venezky, 1970); exceptions were defined as words that do not follow the rules. The regular words were chosen from those that are less frequent in the language to eliminate the pronunciation differences between regular words and exceptions. The words were presented in upper, lower, or mixed cases. The idea was that exception words should be more dependent on a whole-word mechanism than regular words and that upper-case letters are less appropriate for this whole-word mechanism. Therefore, if words are recognized as wholes, and exceptions more so than regular words, we would expect an interaction between upper and lower case and regular versus exception words. No interaction was found, however, and this result argues against the whole word mechanism.

Other evidence against the whole word idea and in support of orthographic regularity has been recorded by Brooks (1974), who translated real English words into an artificial alphabet and asked subjects to learn the real-word responses to the words presented in the artificial alphabet. The same subjects were also asked to learn stimuli that had the stimuli and responses re-paired so that the new alphabet would not be a useful guide to pronunciation. Figure 3.2 lists the alphabets and the stimuli and responses used in the experiment. Note that in the orthographic condition each of the artificial letters corresponds to an English letter. In the paired-associate condition, the stimuli are re-paired with the responses so that the orthographic regularity is lost. If subjects learn to process words as wholes without regard to the orthographic regularity of the letters, then we would expect that the speed of reading the paired-associate stimuli should be the same as that of reading the orthographic stimuli. If a whole word analysis is used, the orthographic structure is useless. In contrast, if letter processing mediates word processing, we would expect that the orthographic structure would facilitate reading performance.

Subjects were asked to read aloud lists of six items as fast as possible without error. Although the paired-associate list was initially read faster than the orthographic list, the asymptotic reading times of highly practiced

FIG. 3.2. Stimuli used by Baron (From "Mechanisms for pronouncing printed words: Use and acquisition" by J. Baron. In D. LaBerge & S. J. Samuels (Eds.), *Basic Processes in Readiing: Perception and Comprehension*. Hillsdale, N.J.: Lawrence Erlbaum Associates, 1977. Copyright 1977 by Lawrence Erlbaum Associates, Inc. Reprinted by permission.)

subjects were significantly faster for the orthographic than for the paired-associate condition. In a second experiment, the component letters were concatenated to form glyphic patterns, making it difficult to recognize the component letters. Even though the glyphic calligraphy was read faster than the words made up of discrete letters, the orthographic patterns were still read faster than the paired-associate patterns at asymptote. Although these results come from a novel paradigm, they support the conclusions of the other research we have reviewed. Words are not recognized as holistic units; letter analysis and the use of orthographic structure must mediate their recognition.

SUMMARY

There is now sufficient experimental evidence to argue that some kind of orthographic regularity facilitates the perception of letter strings. We have set out to determine the nature of this regularity and hope eventually to obtain substantial evidence for constructing a model of the reader's knowledge of orthographic regularity.

In concluding, we return to our concern for phonics instruction, which we expressed earlier in this chapter. If rapid word recognition is essential for competent reading and if orthographic regularity is important for recognition then reading instruction must ensure that students acquire an awareness of orthographic regularity. This awareness might occur simply from exposure to reading, regardless of reading ability. On the other hand, some readers, because of inefficient recognition strategies, might not acquire a sense of orthographic regularity or they might do so only after considerable remedial attention. We suspect that a full sense of orthographic regularity does not develop until at least the middle grades for some readers and, perhaps, much

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