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# The Representation of Sublexical Orthographic-Phonologic Correspondences: Evidence from Phonological Dyslexia

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Although there is considerable evidence that grapheme and body units are involved in assembling phonology from print, there is little evidence supporting the involvement of syllabic representations. We provide evidence on this point from a phonological dyslexic patient (ML) who, as a result of brain damage, is relatively unable to read nonwords. ML was found to be able to perform tasks assumed to reflect processes involved in assembled phonology (i.e. segmentation, orthographic-phonologic conversion, and blending) when the units involved were syllables, but demonstrated considerable difficulty when they were onset, body, or phoneme units. Additionally, both ML and matched controls were much better able to find words in an anagrams task (Treiman & Chafetz, 1987) when they resulted from the combination of segments corresponding to syllables than when they did not. It is suggested that the relationship between print and sound is represented at multiple levels (including the syllable) (Shallice, Warrington, & McCarthy, 1983) and that ML's nonword reading impairment is the result of disruption of representations below the level of the syllable.

Traditional dual-route models of reading (e.g. Coltheart, 1978) suggest that there are two means of obtaining the phonological representation of a written word: (a) by "addressing" a word's lexical entry, which specifies a whole-word phonological representation (the lexical route) or (b) by "assembling" a phonological representation on the basis of spelling-to-sound correspondences (the sublexical route). The lexical route is assumed to be necessary in order to read (out loud) words like HAVE that form exceptions to spelling-to-sound correspondence rules (i.e. words with similar spellings are pronounced differently—WAVE, GAVE, RAVE, SAVE). Evidence for a lexical route has frequently come in the form of null effects of assembled phonology (see Van Orden et al., 1992 for a discussion of this point) and from patients with acquired reading disorders. In support of a sublexical route to phonology, many researchers have observed a "regularity effect"—the finding

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that regular words (words with predictable grapheme-to-phoneme correspondences) are named more quickly than irregular words (Baron & Strawson, 1976; Gough & Cosky, 1977; Stanovich & Bauer, 1978). However, more recent research (Andrews, 1982; Backman, Bruck, Hebert, & Seidenberg, 1984; Seidenberg, 1985; Seidenberg, Waters, Barnes, & Tanenhaus, 1984; Waters, Seidenberg, & Bruck, 1984) indicates that this effect may be restricted to the processing of low-frequency words. Similarly, Glushko's (1979) finding of an effect of "consistency"—the consistency with which orthography is mapped to phonology at the level of the word *body* (the vowel and succeeding consonants)—has also been found to be restricted to low-frequency words (Seidenberg et al., 1984). It has been argued that the restriction of the regularity effect to the processing of low-frequency words indicates that the sublexical route serves as a slower "back-up" to the faster lexical route (e.g. Seidenberg, 1985).

The occurrence of two distinct syndromes—surface dyslexia and phonological dyslexia—suggests a functional separation of the lexical and sublexical routes. In surface dyslexia, an effect of spelling-to-sound regularity on reading (such that regular words are read more easily than irregular words) and the occurrence of regularization errors (reading irregular words as though they were regular) suggest that the lexical route has been damaged and that reading is forced to proceed on the basis of a relatively intact sublexical route. In acquired phonological dyslexia, the patients' relatively spared ability to read words, coupled with their relative inability to read nonwords, suggests that, in this syndrome, the sublexical route is damaged whereas the lexical route is relatively spared.

While most researchers seem to agree that there are both sublexical *and* lexical routes to phonology, there is considerable disagreement concerning the nature of these two routes. Some theorists have suggested an indirect lexical route that proceeds through semantics (e.g. Coltheart, Curtis, Atkins, & Haller, 1993; Morton & Patterson, 1980; Patterson & Shewell, 1987; Plaut, McClelland, Seidenberg, & Patterson, 1996). A semantic lexical route to phonology is suggested by the reading performance of deep dyslexic patients (see Marshall & Newcombe, 1973; Saffran & Marin, 1977). The inability of deep dyslexics to read nonwords indicates impaired assembled phonology. Therefore, their word reading cannot rely on grapheme-to-phoneme conversion and must rely on a lexical route to phonology. Evidence that this lexical route proceeds through semantics comes in the form of word class effects (better reading of concrete than of abstract words) and the occurrence of semantic errors. Evidence for a more direct route from the written word to the spoken word comes from the study of patients who can read irregular words that they do not understand (see Coltheart, Masterson, Byng, Prior, & Riddoch, 1983; Funnell, 1983; Schwartz, Saffran, & Marin, 1980). However, Hillis and Caramazza (1991) have questioned the necessity of postulating a direct lexical route, as it may be the case that the reading of these patients is mediated by the summation of partial semantic information and partial phonological information (resulting from attempts to apply grapheme-to-phoneme correspondence rules). Some theorists (e.g. Morton & Patterson, 1980; Patterson & Shewell, 1987; see also Coltheart et al., 1993) propose both semantic and direct lexical routes.

There is also considerable debate as to how the sublexical route works and, hence, what types of item it is capable of processing. For example, Coltheart and colleagues (Coltheart et al., 1993) propose a three-route model in which the sublexical route is capable of

producing the correct pronunciation for regular words whereas exception words must be read through the lexical route. In their formulation, it is not clear how much a semantic route contributes to skilled oral reading. The class of models proposed by Seidenberg and colleagues (e.g. Plaut et al., 1996; Seidenberg & McClelland, 1989), on the other hand, has two routes: (a) a sublexical route that processes *both* regular and exception words and (b) a semantic route that makes a strong contribution to reading (particularly for low-frequency exception words). In a third class of models (e.g. Shallice, Warrington, & McCarthy, 1983) phonological representations are assembled on the basis of stored orthographic–phonologic correspondences ranging from the level of the individual grapheme up to the level of the whole word (see Taft, 1991, for a similar model that does not incorporate whole word orthographic–phonologic representations). Thus, sublexical and lexical phonology are subsumed under one mechanism. Such a multiple-levels model has been implemented by Norris (1994).

The following discussion of the sublexical route will be organized around two issues: (a) the levels of orthographic–phonologic representations involved in reading and (b) the processes involved in assembling phonology from print. Some researchers argue that the conversion from orthography to phonology proceeds at the level of individual graphemes and phonemes (e.g. Coltheart, 1978; Coltheart et al., 1993) whereas others suggest the involvement of other levels of correspondence (e.g. Patterson & Morton, 1985; Shallice et al., 1983). In the current investigation we present a case study of a phonological dyslexic patient, which sheds some light on how sublexical orthographic–phonologic correspondences are represented and their role in reading.

While traditional dual-route theories (e.g. Coltheart, 1978) suggest that the mapping from orthography to phonology proceeds at the level of individual graphemes and phonemes, there is evidence that other levels of correspondence may be relevant to the assembly process. The observation of a consistency effect suggests that the word-body may be important. Treiman (e.g. Treiman and Zukowski, 1988) has also obtained evidence for the importance of the body along with the onset in the processing of written words. The onset and body are subsyllabic units. In monosyllabic words, the *onset* is the initial consonant or consonant cluster whereas the *body* is the vowel and all following consonants. Thus, in the word BLACK, BL forms the onset of the syllable and ACK forms the body. Treiman and Zukowski found that the pronunciation assigned to a nonword was influenced more by its body than by its onset or vowel grapheme alone. That is, they found that subjects were more likely to assign the phoneme /E/ to the grapheme “ie” when it occurred in CHIEND (which shares its body with the real word FRIEND) than when it occurred in FRIETH or CHIETH. Treiman (Treiman & Chafetz, 1987) has also observed that words are found more easily in anagrams task when the units to be combined correspond to onset and body units (e.g. it is easier to find the word BLACK within the segments [BL OFT ACK FR] than within the segments [BLA FT CK FRO]). Additional evidence for the importance of onset and body units in the processing of written words comes from the demonstration that these sublexical units prime naming of target words containing these units. For example, Bowey (1990) found that primes corresponding to the onset or body of a following target word (e.g. BR followed by BRAND or AIL followed by HAIL) speeded naming times relative to when the primes did not correspond to these units (e.g. BI followed by BIRCH or RAY followed by PRAY).

Whereas Treiman and colleagues have made a strong case for the importance of subsyllabic (onset–body) units in the processing of written words, a much less consistent picture emerges when syllabic units are considered (see Seidenberg, 1989). When subjects are asked to make same–different decisions on words matched in length (number of letters), some researchers have observed an effect of number of syllables on latencies to make “different” responses (e.g. Klapp, 1971), whereas others have observed an effect only on latencies to make “same” responses (e.g. Taylor, Miller, & Juola, 1977). Still others have failed to observe an effect on either type of response (e.g. Barron & Pittinger, 1974). A similar inconsistency results from the use of naming latency, with some researchers observing an effect of number of syllables (Butler & Hains, 1979; Klapp, Anderson, & Berrian, 1973) and some not (Frederiksen & Kroll, 1976; Richardson, 1976).

Another method that has been used to examine the role of syllabic units in the processing of written words involves the brief presentation of written words whose letters are coloured. Prinzmetal, Treiman, and Rho (1986) found that illusory conjunctions (when a letter is erroneously reported as being the colour of another letter in the word) occur more often among letters within the same syllable than among letters that cross a syllable boundary. This effect was observed for words containing orthographically marked boundaries (where syllable boundaries are marked by letter combinations that are illegal within syllables, e.g. NV in ANVIL). Seidenberg (1987), however, observed a syllable effect with words whose syllable boundary was marked by a “bigram trough” (a bigram with a lower frequency than that preceding or following it), but found that orthographically similar pairs with different syllable structure (e.g. WAIVE–NAIVE), behave similarly in this paradigm. Seidenberg (1987, 1989) suggests that the critical factor in the observation of a syllable effect is the presence of a bigram trough at the syllable boundary. However, as pointed out by Rapp (1992), Seidenberg (1987) did not examine words *lacking* a bigram trough at the syllable boundary. Using stimuli with orthographically marked syllabic boundaries, Rapp observed a significant effect of syllable structure on both trough-present and trough-absent stimuli indicating that the presence of a bigram trough is not critical to the observation of a syllable effect. More recently, Carreiras, Alvarez, and de-Vega (1993) observed an effect of the frequency of syllables (in Spanish) on naming and lexical decision times, which they argued could not be accounted for in terms of orthographic redundancy.

The view of reading that emerges from our discussion thus far is that there are at least two different processes by which a phonological representation may be obtained from a written word (lexical vs. sublexical phonology) and that multiple orthographic–phonologic representations (grapheme–phoneme, onset, body, and syllabic units) may be involved in assembling a pronunciation on the basis of spelling–to–sound correspondences.

Additional evidence regarding the operation of the sublexical route comes from neuropsychological case studies (e.g. Beauvois & Derouesne, 1979; Derouesne & Beauvois, 1985; Funnell, 1983; Goodall & Phillips, 1995). According to Beauvois and Derouesne (1979; Derouesne & Beauvois, 1985) there are three distinct stages upon which the sublexical route depends: (a) a *grapheme stage* that parses the written stimulus; (b) *print–to–sound conversion* that operates on the units from Stage a; and (c) a *phonemic stage* in which the sounds obtained in Stage b are assembled into the phonological representation for the written stimulus (see Figure 1 for an illustration of Beauvois and Derouesne’s

stages of assembled phonology. However, we have assumed the involvement of multiple levels of orthography and phonology even though Beauvois and Derouesne only consider graphemes and phonemes). It is argued that disruption to any of these processes results in a pattern of reading performance characteristic of phonological dyslexia. There is some support for such an analysis (see Goodall & Phillips, 1995). For example, Newcombe and Marshall's (1985) patient MS seems to suffer an impairment to graphemic analysis (Stage a), whereas Funnell's (1983) patient WB suffers an impairment in the assignment of phonemes to graphemes (Stage b), and Bub, Black, Howell, and Kertesz's (1987) patient

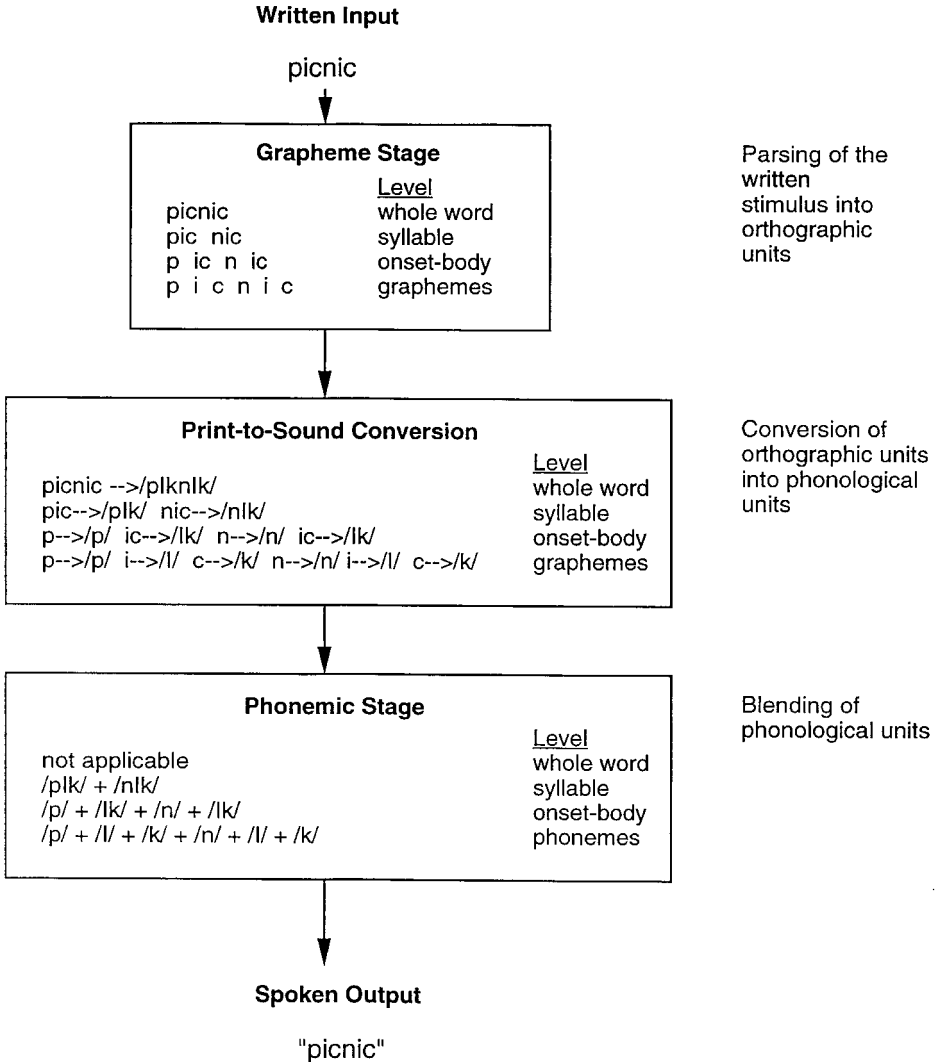


FIG. 1. Beauvois and Derouesne's (1979) stages of assembled phonology illustrated with multiple levels of orthographic and phonological representations.

MV, as well as the patients studied by Patterson and Marcel (1992), seems to have an impairment in phonological blending (Stage c). More recently, Goodall and Phillips (1995) concluded that their patient AN has deficits in print-to-sound conversion and phonological blending, but spared segmentation abilities (graphemic and phonological). In a further investigation of WB's impairment, Patterson and Marcel (1992) found that this patient was unable to perform phonological blending with nonword targets.<sup>1</sup> Berndt, Haendiges, Mitchum, and Wayland (1996) reported 11 patients who all showed evidence of impairment to all three of the components of nonword reading. Additionally, for some patients, they observed an influence of segment size on performance. These studies suggest that nonword reading impairments result when any of the stages of nonword reading have been disrupted.

An issue that is not addressed in Beauvois and Derouesne's analysis is how the conversion from print to sound takes place. There has been relatively little neuropsychological research addressing the issue of the nature of the orthographic units and phonological units involved in reading. An exception in this regard is the work of Shallice et al. (1983; see also Berndt et al., 1996; Funnell, 1983). Based on work with a surface dyslexic patient (HTR), Shallice et al. (1983; see also Shallice & McCarthy, 1985; Shallice & Warrington, 1980) suggested that correspondences between orthography and phonology are represented at multiple levels. Their data suggested that HTR's surface dyslexia reflected a reliance upon smaller units of orthographic-phonologic correspondence (e.g. grapheme-phoneme, subsyllabic units) in the face of disruption to larger units of correspondence (e.g. word or morpheme units). More specifically, they observed an effect of degree of regularity on HTR's reading performance such that an "irregular" word (where "regularity" is defined in terms of the vowel) was more likely to be read correctly if that irregular pronunciation were the most frequent one for the subsyllabic cv or vc than if the most frequent pronunciation were the regular one. An effect of degree of regularity is not predicted by models that posit that assembled phonology proceeds solely on the basis of grapheme-to-phoneme correspondences. Thus, there is evidence both from studies with normal subjects and studies with patients with acquired dyslexias that reading is influenced by the relationship between multiple levels of orthography and phonology.

Shallice et al. (1983) provide an interpretation of surface dyslexia in terms of a selective disruption of word or morpheme units. It is of interest to determine whether a similar interpretation (i.e. in terms of the disruption of representational units) is possible for phonological dyslexia. With that goal in mind, we investigated the word and nonword reading abilities of an acquired phonological dyslexic, ML. This investigation was initially spurred by the observation that ML's nonword reading, although very poor, was not entirely abolished. Preliminary testing suggested the possibility that ML's nonword reading is mediated by syllabic representations (see later). We were therefore interested in whether the pattern of disruption of the sublexical route could be attributed to a disruption of one or more of the processes hypothesized by Beauvois and Derouesne (i.e.

<sup>1</sup> The pattern of performance of some patients on phonological tasks has led to the suggestion that phonological dyslexia is a "symptom" of a more generalized phonological deficit (see Farah, Stowe, & Levinson, 1996; Friedman, 1996; Patterson, Suzuki, & Wydell, 1996; Sasanuma, Ito, Patterson, & Ito, 1996). However, it appears that not all patients can be accommodated within this account.

orthographic segmentation, conversion of orthographic units into phonological units, and blending of phonological units) (1979; Derouesne & Beauvois, 1985), or whether it might be better explained in terms of the disruption of different units of orthographic–phonologic correspondence (those below the level of the syllable). Testing of ML’s nonword reading was organized by administering tasks designed to tap processes at the three stages hypothesized by Beauvois and Derouesne. At each stage, processing of different sizes of orthographic–phonologic units was assessed (see Figure 1). To the extent that ML’s performance is found to vary with the task, but not with the level of representation involved, there would be evidence that ML’s nonword reading impairment is due to a disruption of the processes involved in assembling phonology from print. On the other hand, if ML’s performance is found to vary with the level of representation involved, but not with the task, then there would be evidence that his impairment is due to the disruption of orthographic–phonologic representations. We were particularly interested in whether ML’s performance on the various tasks would reveal syllabic effects as there was some indication in initial tests of his nonword reading that these units might be important for him. As indicated earlier, the evidence is inconsistent regarding a role for syllabic representations in reading. Therefore, the observation of such an effect on the word and nonword reading of this phonological dyslexic patient would be an important finding.

### PATIENT DESCRIPTION

ML is a 57-year-old white male who suffered a left hemisphere cerebral vascular accident in May, 1990. CT scan revealed an infarction involving the left frontal and parietal operculum. Atrophy in the left temporal operculum was noted, as was mild diffuse atrophy. ML had completed two years of college study and prior to his injury had been employed as a draughtsman. ML exhibits mild agrammatism and word-finding difficulties in his spontaneous speech.

ML’s word reading is mostly intact as reflected by his performance on word lists obtained from Roeltgen, Cordell, and Sevush (1983) and from the Psycholinguistic Assessments of Language Processing in Aphasia (PALPA) (Kay, Lesser, & Coltheart, 1992). On the Roeltgen et al. word lists ML obtained 100% (40/40) correct on nouns, 75% (30/40) correct on function words, and 98% (44/45) and 96% (43/45) correct on regular and irregular words, respectively (matched on imageability, length, word frequency, and word class) (see Table 1). ML’s errors on function words were generally function word substitutions. On the PALPA test of grammatical class reading, ML obtained 100% (20/20) correct for nouns, adjectives, and verbs, and 85% (17/20) correct for function words. Thus, although ML reads most word classes at a very high level, he appears to have a slight impairment in reading function words. A difficulty with function word reading is commonly associated with phonological dyslexia (see Beauvois & Derouesne, 1979; Friedman, 1995; Patterson, 1982) suggesting the possibility that nonwords and function words are read through the same process (Patterson, 1982). However, arguing against this notion are reports of patients who have severe nonword reading deficits, but good word reading even for function words (Caramazza, Miceli, Silveri, & Laudanna, 1985; Funnell, 1983). We will not comment on the possible causes of ML’s



TABLE 1  
Word Reading

<i>Word Type</i>	<i>Score</i>	
	<i>Roeltgen<sup>a</sup></i>	<i>PALPA<sup>a</sup></i>
Nouns	100	100
Adjectives		100
Verbs		100
Function	75	85
Regular	98	
Irregular	96	

<sup>a</sup> In percentages.

Nonword Reading

<i>PALPA Nonwords</i>	<i>Example</i>	<i>Score</i>
3 letter	cug	2/ 6
4 letter	boak	2/ 6
5 letter	snite	4/ 6
6 letter	dringe	0/ 6

<i>Roeltgen Nonwords</i>	<i>Simple</i>	<i>Score</i>	<i>Complex</i>	<i>Score</i>
2 phoneme	ep	6/ 10	aub	5/ 10
3 phoneme	nud	4/ 10	shev	4/ 10
4 phoneme	scod	4/ 10	tharp	2/ 10
5–7 phonemes	epzim	2/ 4	endurf	0/ 4

difficulty in reading function words beyond indicating that it does not merely reflect an effect of imageability on his reading performance—he reads high- and low-imageability nouns (Kay et al., 1992) at about the same level (39/ 40 and 37/ 40 for high and low imageability nouns, respectively) (see Bartha & Martin, in preparation, for other evidence on this issue).

ML's nonword reading was assessed using a set obtained from the PALPA (Kay et al., 1992) in which the nonwords were monosyllabic and varied on number of letters. He was also tested on nonword lists obtained from Roeltgen et al. (1983). This set varied on number of phonemes and complexity (i.e. the size of graphemes involved—one letter vs. two letters). In sharp contrast to his high level of performance on word reading (almost perfect performance on all classes of words except function words), ML only obtained 38% correct across the two sets of nonwords with a slight indication of poorer performance with longer nonwords than with shorter nonwords (see Table 1). Good word reading and relatively poor nonword reading are the defining features of phonological dyslexia. We will return to a more detailed discussion of ML's nonword reading later.

ML performs well on tests of single word processing as evidenced by his performance on tasks obtained from the Philadelphia Comprehension Battery (Saffran, Schwartz,

Linebarger, Martin, & Bochetto, 1989): auditory lexical decision (99% correct), auditory discrimination (97% correct), and naming (98% correct) (see Martin & Lesch, 1996).

ML suffers from a short-term memory (STM) impairment, which is reflected in his memory span of 2.33 items for word lists and 2.20 items for nonword lists (see Martin & Lesch, 1996, for more detailed information). Thus, ML's recall benefits little from the semantic information contained within words. However, ML's span performance does reveal standard effects of phonological similarity and mode of presentation (auditory vs. visual) indicating that, although still impaired, he has some ability to retain phonological information. Elsewhere (see Martin & Lesch, 1996) we have interpreted ML's STM deficit in terms of separate (but interactive) capacities for retaining semantic and phonological information: Although ML's ability to retain phonological information is relatively intact, recall suffers from the lack of semantic support. Consistent with this interpretation, ML's errors in recall are generally phonologically related items indicating that some phonological information has been retained but that insufficient semantic information is available to select the appropriate target from a pool of phonologically similar competitors. Additionally, recall of early list items is affected by imageability. In other formulations, Patterson and colleagues (Graham, Hodges, & Patterson, 1994; Patterson & Hodges, 1992; Patterson, Graham, & Hodges, 1994; Patterson, Suzuki, & Wydell, 1996) have suggested that the loss of semantic support results in phonological representations becoming "unglued".

Most of the testing reported here occurred between September 1993 and May 1997.

## EXPERIMENTAL TASKS

### Orthographic Segmentation

In order to translate print to sound, it is first necessary to parse the written stimulus into the units relevant to the translation process (see Figure 1). Although Beauvois and Derouesne (1979) term this the *grapheme stage*, the research reviewed earlier suggests the importance of orthographic units larger than the grapheme, such as the onset, body, and syllable. Therefore, we investigated ML's ability to segment written stimuli into these units.

*Syllables.* ML was asked to mark syllable breaks in 31 written words varying from 2 to 4 syllables in length (e.g. *future*, *orchestra*, *cemetery*). For all of the syllable tasks reported in this paper, syllable boundaries were determined by using the syllabification provided by the dictionary. ML performed at a high level (see control performance reported later) in segmenting the words (77% items correct; 80% segments correct). Of his errors, 4/7 involved two-syllable words ending with "-er" (e.g. *blunder*).

*Onset-body Units.* We also assessed ML's ability to segment one-syllable written words into onset and body units (e.g. *cat*, *beef*, *phone*). We asked ML to think about words that rhyme and to focus on that part of the word that is shared among rhyming words (the word-body, e.g. *bed*, *red*, *shed*). He was instructed to place a mark separating that portion of the word from the rest of the word and was given several

examples. ML found this task very difficult and obtained only 3/ 15 (20%) items correct. Erroneous segmentations included bla/ ck and be/ ef.

*Graphemes.* Finally, ML was given an orthographic segmentation task in which he was asked to mark graphemes (single letters or groups of letters corresponding to an individual phoneme) in words (e.g. shy, boot, coat). It was explained to ML that sometimes two written letters combine to produce one sound, and he was given several examples to demonstrate this. However, he performed quite poorly on this task, obtaining only 8/ 15 (53%) items correct. When performance was scored for number of graphemes marked correctly, he obtained 27/ 48 (56%) graphemes correct. Erroneous segmentations included st/ e/ ak and co/ at.

## Performance of Control Subjects on Orthographic Segmentation

Control subjects of about the same age and education level as ML were tested on all the tasks administered to ML. As can be seen in Table 2, ML's pattern of performance differed from the pattern shown by all six control subjects in that he showed great difficulty with onset-body and grapheme units, whereas control subjects showed little difficulty with these units. Although ML's performance with syllable units was clearly within the range of the controls (see Table 2), he performed well outside the range for onset-body and grapheme units. It should be noted that ML and several of the control subjects performed at well below-perfect levels on the syllable task. This is undoubtedly partly due to the fact that the orthography does not always carry explicit cues to syllable boundaries. In fact, some sounds straddle the syllable boundary and can be considered ambisyllabic (i.e. / r/ in

TABLE 2  
A Comparison of the Performance of ML and Control Subjects on the  
Orthographic Segmentation Tasks

<i>Control Subjects</i>	<i>Percentage Correct</i>					
	<i>Syllable</i>		<i>Onset-body</i>		<i>Grapheme</i>	
	<i>Items</i>	<i>Segments</i>	<i>Items</i>	<i>Segments</i>	<i>Items</i>	<i>Segments</i>
PS	100	100	100	100	100	100
PH	81	76	100	100	87	88
MB	90	93	100	100	87	94
MW	84	88	100	100	100	100
TP	61	72	100	100	93	96
HF	71	76	80	80	100	100
Mean	81	84	97	97	95	96
Range	61-100	72-100	80-100	80-100	87-100	88-100
ML	77	80	20	20	53	56

“sparrow”). Additionally, there are different theories of syllabification. For the current study, we used the syllabification provided by the dictionary. However, some researchers (e.g. Treiman, personal communication) are investigating how individuals syllabify different types of stimuli.

## Phonological Segmentation

In the second stage of assembled phonology (print-to-sound conversion) proposed by Beauvois and Derouesne (1979), the units from the grapheme stage are converted into their corresponding sounds (see Figure 1). In learning to read, we learn to associate written units with spoken units. This process would seem to entail the ability to extract the relevant phonological units from spoken words (because the conversion process proceeds over units smaller than the word). Thus, in order to establish initially the phonological representations involved in reading, the beginning reader would need to have some awareness of the structure of spoken language. Morais, Cary, Alegria, and Bertelson (1979) have put forward an interactionist view of the relationship between phonological awareness and alphabetic literacy. According to this view, phonemic awareness is both a cause and a consequence of alphabetic literacy. There is evidence that speech segmentation skills develop as a result of learning to read—ex-illiterates (those with a rudimentary ability to read and write) demonstrate an ability to analyse speech into phonemes (they perform at a high level in phoneme deletion and addition tasks), whereas illiterates do not (see Morais, Bertelson, Cary, & Alegria, 1986; Morais et al., 1979). Thus, learning the mappings between spoken language and written language seems to increase phonological awareness. However, whether “phonological awareness” is important in skilled reading is not so clear. That is, once one has established mappings between orthographic and phonological units the ability to blend the phonological outputs would be critical, whereas the ability to segment spoken words might not. Nonetheless, we thought it of interest to determine whether ML’s ability to extract phonological units from spoken words would depend crucially upon the nature of the unit involved (as it had in orthographic segmentation). Whether ML can segment speech into phonemes, onset-body units, and syllables may have important implications for whether he can re-learn sublexical mappings from orthography to phonology.

*Syllables.* ML was given auditory words (the two- to four-syllable words used in the orthographic segmentation task) and was asked to produce their constituent syllables. His performance was perfect.

*Onset-body Units.* Additionally, ML was asked to produce onset and body units from real words (e.g. “bl” and “ack” from “black”). Since it is not possible to produce some consonant clusters in isolation, responses that included a reduced vowel were scored as correct. He obtained 0/15 items correct—for no individual item did he accurately produce the onset or the body. Errors included failures to include any segmentation (slip → “slip”) and incorrect segmentations (e.g. flirt → / fɪl/ - / ɹt/ ; sock → / sɒk/ . . . / sɔk/ . . . / sɔk/ - / k/ ).

*Phonemes.* ML was asked to produce the phonemes contained within one-syllable words consisting of three phonemes (e.g. “cat”). As was the case with the onset units, some phonemes cannot be produced in isolation (e.g. stop consonants). Therefore, responses that included a reduced vowel were scored as correct. ML never succeeded in producing all the phonemes contained within a single word (0/ 15 items correct). However, he showed some ability to produce the initial phoneme (4/ 15), but quite often he produced a syllable that sometimes corresponded to the initial consonant and vowel (3/ 15), but sometimes did not (e.g. “mit” → / mɛ/ ) (1/ 15). ML correctly produced 9/ 45 of the phonemes. Usually, his responses were a combination of individual phonemes, syllables, and letter names (e.g. rig → / rɪ/ . . . / kɪ/ . . . “a” . . . “g”; hen → / tɪ/ . . . / hɛn/ . . . “n”).

In light of ML’s severely restricted STM capacity, it seemed possible that his poor performance in producing constituent phonemes could be partly due to the memory load entailed in retaining the words while sounding them out. In an attempt to decrease the memory load, we asked ML to produce the constituent phonemes in written words (the same three-phoneme, one-syllable words used with auditory presentation). As ML has difficulty with grapheme segmentation, it was not clear whether written presentation would aid performance. However, ML is able to read written words quite well and this should enable him to “refresh” the whole-word phonology while he is attempting segmentation. Again, however, he never succeeded in producing all the phonemes contained within a single word (0/ 15). ML correctly produced 15/ 45 of the phonemes—however, these phonemes were scattered among letter names, productions of the whole word, and combinations of phonemes.

## Performance of Control Subjects on Phonological Segmentation

As can be seen in Table 3, ML’s poor performance on onset–body and phoneme units is in stark contrast to the excellent performance of the control subjects: Although ML’s performance fell within the range of controls on syllable segmentation, his performance was at floor on onset–body units and phoneme units, whereas the performance of the controls was at ceiling.

## Summary of Segmentation Results

ML performs well when his task is to segment visually or auditorily presented stimuli into constituent syllables. However, when asked to segment stimuli into graphemes/phonemes or into onset–body units, ML demonstrates considerable difficulty in performing the task. A comparison of ML’s performance with that of control subjects indicates that he performs at a normal level when the units involved are syllables, but performs at well below normal levels when the units are graphemes/phonemes or onset–body units.

TABLE 3  
A Comparison of the Performance of ML and Control Subjects on the  
Phonological Segmentation Tasks

<i>Control Subjects</i>	<i>Percentage Correct</i>					
	<i>Syllable</i>		<i>Onset-body</i>		<i>Phoneme</i>	
	<i>Items</i>	<i>Segments</i>	<i>Items</i>	<i>Segments</i>	<i>Items</i>	<i>Segments</i>
PS	100	100	100	100	100	100
PH	100	100	100	100	100	100
MB	100	100	100	100	100	100
MW	100	100	100	100	100	100
TP	100	100	100	100	100	100
HF	94	99	100	100	100	100
Mean	99	99	100	100	100	100
Range	94-100	99-100	N/ A		N/ A	
ML	100	100	0	0	0	20

## CONVERSION OF ORTHOGRAPHIC SEGMENTS INTO PHONOLOGICAL SEGMENTS

According to Beauvois and Derouesne (1979), assembled phonology requires *segmentation* of orthographic stimuli into the relevant units, the *conversion* of these orthographic units into their corresponding phonological units, and the *blending* of these phonological units (see Figure 1). Thus far, the data we have reported from ML suggest that he is able to segment both orthographic and phonological representations when the relevant unit is the syllable. However, performance suffers considerably when other units are involved. What about ML's ability to convert orthographic segments into phonological segments? ML's ability to convert from orthography to phonology was examined at the levels of the syllable, onset-body, and letter units.

### Nonword Reading

On an initial testing of ML's nonword reading, ML performed very poorly. As reviewed earlier (see Table 1), ML obtained only 38% correct across two sets of nonwords. On the PALPA nonwords (Kay et al., 1992) 11/ 16 errors were lexicalizations, whereas 20/ 41 errors on the Roeltgen et al. (1983) nonwords were lexicalizations. ML's tendency to produce real words in response to nonword stimuli suggests a strong lexical influence on his nonword reading attempts. It is interesting to note that occasionally, when ML was able to give a correct response, the nonword corresponded to the initial syllable of a real word, e.g. "rab" (rabbit), "mur" (murder). This observation raised the possibility that ML may be able to retrieve sublexical phonological representations when they correspond to syllable units in words.

## Reading of Nonwords Corresponding to Sublexical Units of Words

*Syllables.* To test the possibility that ML is able to retrieve phonological representations for syllabic units when they correspond to a syllable from a word, we asked ML to read nonwords corresponding to the initial segment of real words. Of these items, 34 corresponded to the initial syllable of real words (syllable nonwords) (e.g. “flut”, which forms the first syllable of “flutter”), whereas the other 34 formed the initial segment of real words but never corresponded to an initial syllable of a real word (control nonwords) (e.g. “furb” from “furbish”). The two types of nonword were approximately matched in terms of bigram frequency (Mayzner & Tresselt, 1965), neighbourhood size ( $N$ ), and summed frequency (Francis & Kučera, 1982) of all words containing the segment in any position (this was done by searching the American Heritage Electronic Dictionary, 1992). These stimulus characteristics are presented in Table 4. ML was tested twice on these stimuli (mixed presentation of syllable and control items) in sessions separated by at least one week. As can be seen in Table 5, ML’s level of performance was similar across the two sessions (Session 1: 51% correct; Session 2: 47% correct), and he read the syllable nonwords at a much higher level (overall: 71% correct) than the control nonwords (overall: 28% correct). The difference in performance ( $\Delta$ ) was significant for Session 1,  $\Delta = 39\%$  (24/34 vs. 11/34),  $\chi^2 = 9.95$ ,  $p < .01$ , as well as for Session 2,  $\Delta = 47\%$  (24/34 vs. 8/34),  $\chi^2 = 15.11$ ,  $p < .01$ . Lexicalizations were the most common error type: 5/10 and 6/10 errors for syllable stimuli for Sessions 1 and 2, respectively, and 14/23 and 20/26 errors for the control stimuli.

To investigate further ML’s reading of syllabic units from words, we constructed a second set of stimuli that corresponded to medial or word-final segments (e.g. syllable: “vorce” from “divorce”; control: “droom” from “bedroom”). These nonwords were also matched on bigram frequency,  $N$ , and summed frequency of items containing the segment (see Table 4). There were 27 syllable nonwords and 27 control nonwords. ML was tested twice on these stimuli (mixed presentation of syllable and control items). As can be seen in Table 5, ML’s level of performance was again similar across the two test sessions (though a bit lower in session 2), and his level of performance was much higher for the syllable than for the control nonwords. The difference in performance was significant for

TABLE 4  
Stimulus Characteristics of Syllable and Control Nonwords Used in Reading and Repetition

		<i>Bigram Freq</i>		<i>N</i>		<i>Summed Freq</i>	
		<i>M</i>	<i>SD</i>	<i>M</i>	<i>SD</i>	<i>M</i>	<i>SD</i>
Word-Initial	syllable	37.83	39.78	3.79	2.95	56.32	115.70
	control	40.66	41.58	5.09	2.99	60.71	129.43
Non-initial	syllable	40.49	28.50	4.44	3.29	104.19	186.05
	control	43.89	35.97	4.74	3.69	101.00	178.67

TABLE 5  
ML's Performance in Reading and Repetition of Nonwords of  
Different Types

		<i>Percentage Correct</i>			
		<i>Read 1</i>	<i>Read 2</i>	<i>Repeat 1</i>	<i>Repeat 2</i>
Word-initial	syllable	71	71	74	82
	control	32	24	65	79
Non-initial	syllable	81	67	67	74
	control	30	19	85	89
Body		16	24	84	89
Onset		9	23	77	91

Session 1,  $\Delta = 51\%$  (22/ 27/ vs. 8/ 27),  $\chi^2 = 14.70$ ,  $p < .01$ , as well as for Session 2,  $\Delta = 48\%$  (18/ 27 vs. 5/ 27),  $\chi^2 = 12.80$ ,  $p < .01$ . For Sessions 1 and 2 there were 4/ 5 and 8/ 9 lexicalization errors for the syllable stimuli and 15/ 19 and 14/ 22 for the control stimuli. Level of performance was similar for the word-initial and nonword-initial stimuli.

*Onset-body Units.* ML was also asked to read nonwords corresponding to onset or body units in real words (e.g. "bl" and "ack" from the word "black"). He was tested twice on these stimuli in test sessions at least one week apart. Although ML's nonword reading improved when the nonwords to be read corresponded to syllables within real words, ML's nonword reading did not seem to benefit from having the nonwords correspond to onset units (Session 1: 2/ 22 correct; Session 2: 5/ 22 correct) or body units (Session 1: 4/ 25 correct; Session 2: 6/ 25 correct). Error responses for the onset stimuli were generally words beginning with the consonant cluster (e.g. tr → tree; gr → grow), but were occasionally the consonant cluster with a vowel attached (e.g. cl → "clo"; pl → "plo"). This suggests that ML may have been using a lexical strategy to read these items. That is, he may have been able to come up with a word beginning with the given onset, which he then attempted to segment down to the appropriate unit. ML's deficits in the segmentation tasks reported above suggest (consistent with his performance on the reading of onset units) that this would not be a very successful strategy.

For the body stimuli, there was a variety of error types. some examples of errors include: orse → "orst"; atch → "attach"; outh → "use" . . . "u" . . . "u" . . . "out"; urt → "hurt"; udge → "u" . . . "crunch"; eath → "eat".

*Processing of Letters.* ML does fairly well in naming individual letters, obtaining 23/ 26 correct. When given letter sounds, ML was able to provide the corresponding letter name on 15/ 22 trials. When provided with the written letter, ML produced an appropriate sound for only 9/ 26 letters. It is interesting to note that ML continued to have difficulty even when it was suggested that he think of a word beginning with the given letter and then segment off the initial sound (see Funnell, 1983).



## Performance of Control Subjects on Nonword Reading

We expected that control subjects would make few errors in unspeeeded nonword reading. Therefore, we recorded reaction times to name the nonwords that ML had been asked to read. Subjects saw nonwords one at a time in the middle of a computer screen and were asked to name the nonword as quickly and as accurately as possible. Presentation was blocked by type of nonword (as was the case for ML). The mean error rate was 3%. The reaction time data are presented in Table 6 along with the percent errors for ML. The data were subjected to a one-way analysis of variance with nonword type as a within-subject factor. There was no main effect of nonword type;  $F(5, 20) = 1.98, p = .13$ . Reaction times appeared to be longest in the onset condition. This is not surprising, given that we are not normally asked to read consonant clusters. It can be seen that ML had the most difficulty with the onset units—the units that produced the longest naming times for controls. Otherwise, there was little correspondence between ML's performance and that of the controls—ML was significantly worse at reading control nonwords than syllable nonwords, whereas for the control subjects, there was little difference between non-initial syllables and their controls (reaction times were 10 msec longer to controls) and the difference was in the opposite direction for the initial syllables and controls (21-msec difference). However, these differences did not approach significance. Additionally, it appeared that body units had the shortest latencies. If latency can be assumed to reflect difficulty of processing, then this result would be inconsistent with the idea that ML suffers from a global decrement to the sublexical reading process in which it might be expected that the most difficult tasks would be the most impaired.

## Conversion without Output

In order to assess whether ML's nonword reading deficit is related to a difficulty with production, we assessed ML's ability to convert from orthography to phonology in a task that does not require output. In this task ML was presented with each item that he had

TABLE 6  
Performance of Control Subjects on Nonword Reading

	<i>Reaction Time<sup>a</sup></i>					
	<i>I-Syll</i>	<i>Control</i>	<i>NI-Syll</i>	<i>Control</i>	<i>Body</i>	<i>Onset</i>
FM	675	688	764	781	570	758
PH	578	542	546	572	492	604
MB	667	650	662	652	647	651
MW	700	656	660	676	679	669
PS	510	488	463	464	485	549
Mean	626	605	619	629	575	646
Range	510–700	488–688	463–764	464–781	485–679	549–758
ML Errors <sup>b</sup>	29	72	26	76	80	84

<sup>a</sup> In msec. <sup>b</sup> In percentages.

been asked to read earlier (syllable vs. control, onset, and body) and was given a pronunciation that either did or did not correspond to the nonword. Incorrect pronunciations differed from the correct pronunciation by one phoneme, and the position of the difference was varied. Each item was paired with an incorrect and a correct pronunciation. ML was asked to judge whether or not a pronunciation was correct. If ML's reading impairment is related to a difficulty with production, then he should perform at a relatively high level on this task. Contrary to this prediction, ML performed quite poorly. Items were scored as correct if he rejected the incorrect pronunciation *and* accepted the correct pronunciation. ML obtained 7/25 correct for the body units and 7/22 correct for the onsets. He obtained 7/27 correct for non-initial syllables against 3/27 correct for their controls, and 14/34 correct for the initial syllables against 4/34 correct for their controls. Thus, the pattern of performance on this judgement task was similar to the pattern on the reading tasks. The similar pattern of performance in a task not requiring output suggests that ML's poor nonword reading cannot be accounted for in terms of an output problem. ML's low level of performance on this task (which stemmed from his willingness to accept incorrect pronunciations) suggests that there may be a high level of "noise" in the reading system.

### Summary: Orthographic–Phonologic Conversion

ML performs poorly when asked to produce the sound of a written letter or to read nonwords sharing onset- or body-status with real word segments. However, ML shows a clear advantage in reading nonwords when they correspond to a syllable within a real word relative to when they form the initial segment of real words but do not have syllable status within a real word. This difference emerged even though the two types of stimuli (syllable vs. control) were matched on several variables. The results suggest that at least one sublexical unit—the syllable—plays a role in ML's nonword reading. An account in terms of an output problem seems unlikely given the similar pattern of performance on the conversion without output task.

### Repetition of Nonwords

ML's greater accuracy in reading single-syllable nonwords that correspond to syllables within real words compared to those that do not correspond to syllables within real words might possibly be related to his short-term memory deficit. That is, in attempting to produce a nonword, it is possible that he has better ability to hold onto the phonological representation of syllables in real words because these syllables activate lexical representations to some extent and therefore feedback from the lexical level could help to maintain these units in short-term memory (see Martin & Saffran, 1992a, 1992b). Also, units corresponding to syllables of real words might be more easily articulated because of prior practice in producing these syllables. To address these issues, ML was asked to repeat the control and the syllable nonwords. If short-term memory is the source of the difference in reading the two types of nonwords, he should show the same pattern in repetition. However, it should be noted that repetition is an easier task than is reading because the phonological specification of the nonword is provided—that is, the phonological system is more strongly activated by spoken input than by written input (see Patterson

et al., 1996). For this reason alone, ML's repetition performance may not mirror his reading performance. However, if ML's repetition performance is not at ceiling, and his reading difficulties are due to articulatory or short-term memory problems, then there should be some relation between his reading and repetition performance. ML was tested twice on repetition of the nonwords that he had been asked to read. As can be seen in Table 5, ML's repetition performance was not at ceiling. However, there appears to be little relation between reading performance and repetition performance: For the word-initial syllable and control nonwords, performance was slightly better for syllables than for control nonwords (over session: syllable 78% vs. control 72%). However, for the nonword-initial stimuli, the difference was in the other direction (over session: syllable 70% vs. control 87%). Additionally, repetition performance was very high for those items causing ML the most difficulty in reading: the onset and body units. The difference in patterns of performance across reading and repetition suggests that ML's nonword reading pattern should not be attributed to short-term memory or articulatory factors.

All five control subjects repeated all the word-initial syllable and control nonwords correctly and three control subjects repeated all the nonword-initial syllable and control words correctly. One subject made one lexicalization error on a syllable item, and another made one error on a syllable item and two lexicalization errors on control items. None of the control subjects made any errors on repetition of onset and body stimuli.

ML's performance on the tasks we have presented thus far is consistent with the suggestion that his nonword reading impairment is due to a disruption to certain levels of sublexical representation and not to a disruption to processes underlying assembled phonology—ML is able to segment both orthographic and phonological representations when the relevant unit is the syllable, but performs quite poorly when the relevant units are onsets and bodies or phonemes. Furthermore, ML's nonword reading does not benefit from having the nonwords correspond to onset or body units from real words, but does benefit from having them correspond to syllables within real words.

### Phonological Blending (Auditory Presentation)

We have evidence that the processes involved in the first two stages of assembled phonology are relatively intact in ML: He is able to segment orthographic and phonological representations, and he is able to convert orthographic units to phonological units. However, his performance depends upon the size of the units involved—performance is substantially better with syllable units than with smaller units. In the third stage suggested by Beauvois and Derouesne (1979), the *phonemic stage*, the sounds obtained in Stage 2 are assembled into the phonological representation for the written stimulus (see Figure 1). We therefore assessed ML's ability to blend different phonological units to produce words. We presented ML with auditory words segmented into individual phonemes, syllables, or onset–body units. We explained to ML that he would hear words being sounded out (sound by sound, syllable by syllable, or split into onset–body units) and that he was to report the word resulting from the blending of these units. He was given several practice trials and was told the appropriate responses for these trials in an attempt to ensure that he understood the task.

*Syllables.* ML performed at a high level when the segments to be blended were syllables (19/20 correct). His one error on the syllable-blending trials was making the response “celery” to the syllables contained within “salary”.<sup>2</sup>

*Onset–body units.* ML was also given 49 words with a CCVCC structure (e.g. BLACK). These words were divided at their onset–body boundary (“bl” - “ack”) and ML was asked to blend the segments to produce a word. ML obtained 20/49 correct. Of the erroneous responses, 7/29 were failures to respond. Other error types included two-word responses (2/29) (e.g. “gr” - “unt” → “great aunt”; “pl” - “uck” → “pull-up”) and multisyllabic responses (11/29) (e.g. “pr” - “ess” → “purchase”) that generally bore some phonological relationship to the target item.

In order to investigate further the nature of ML’s difficulties with this phonological blending task, a second version of the task was administered that would better allow for the determination of whether ML’s performance varies with type of onset. One possibility is that ML has difficulty blending onsets that require schwa-deletion before blending (i.e. stops). In this task all stimuli had a CVC or CVCC structure (rather than CCVCC) as there are fewer constraints on phonemes that can occur in word-initial position than on those that can occur as the second consonant in a word-initial consonant cluster. This would allow us to vary more systematically the type of onset involved. We used a set of 15 bodies in combination with six different types of onset (nasal, stop, affricate, fricative, liquid, and glide) resulting in a total of 90 onset–body pairs. The different onset–body pairings were presented in pseudo-random fashion.

The stop, affricate, and glide onsets all require schwa-deletion before blending, whereas the nasal, fricative, and liquid onsets do not. Therefore, if it is schwa-deletion that is causing ML’s difficulty, then he should perform at a much higher level with the nasal, fricative, and liquid onsets than with onsets that require schwa-deletion.

ML obtained 15/90 (17%) correct: 10/45 correct for onsets requiring schwa-deletion and 5/45 correct for onsets not requiring schwa-deletion. Therefore, we obtained no evidence that ML’s poor performance in onset–body blending is related to a difficulty with schwa-deletion. The majority (53/75) of ML’s erroneous responses consisted of failures to respond. For 8/75 errors ML produced a multisyllabic or multi-word response (this type of response occurred for all types of onset). Occasionally, error responses shared an onset (wives → walk) or a body (meek → week). The discrepancy in performance between the two tasks (Task 1: 20/49; Task 2: 15/90) merits some comment. In Task 1, because of the structure of the targets, the second consonant of the consonant cluster was repeated over many trials (i.e. there is a limited set of consonants that can occur in that position). This could have benefited ML’s performance in Task 1 relative to Task 2. Another possibility is that ML’s perception or memory is more stable for consonant clusters than for individual phonemes. Again, this would result in a benefit for Task 1 performance relative to Task 2 performance.

<sup>2</sup> Although we have classified “celery” as an erroneous response to the syllables contained within “salary”, it may be the case that the response was actually correct and reflects differences between the examiner’s New England accent and ML’s Texan accent.

*Phonemes.* ML failed to make a single correct response on the phoneme-blending trials—indeed, he was very unwilling to make any response at all. His complete inability to perform this task is evident by his response on one trial when he was pressed to respond—to the phonemes contained within “tree”, he responded “rough”.

## Performance of Control Subjects on Phonological Blending (Auditory Presentation)

As can be seen in Table 7, ML performs at a near-normal level when asked to blend syllables, but performs well below the range of the control subjects when asked to blend onsets and bodies or phonemes. No individual control subject showed a pattern similar to that of ML.

## Orthographic/Phonological Blending (Visual Presentation)

In order to provide a test of ML’s ability to blend orthographic/phonological units, we decided to test ML on the anagrams task introduced by Treiman and Chafetz (1987). In this task, the subject sees four word fragments (e.g. BL OFT ACK FR) and is asked if any two fragments can be joined to form a word. Although the units to be blended in this task are presented in the visual modality, we would argue that performance of the task may rely upon the manipulation of phonological units. Treiman and Chafetz found that subjects were quicker to find the words when the segments corresponded to onset and body units than when they did not correspond to these units, which suggests that onset and body units are functional in visual word recognition (see also Bowey, 1990; Treiman &

TABLE 7  
A Comparison of the Performance of ML and Control Subjects on the Phonological Blending (with auditory presentation) Tasks

<i>Control Subjects</i>	<i>Percentage of Items Correct</i>		
	<i>Syllable</i>	<i>Onset-body</i>	<i>Phoneme</i>
PS	100	100	100
PH	100	98	85
MB	100	100	80
MW	100	100	100
TP	100	96	85
HF	100	100	95
Mean	100	99	91
Range	N/ A	96–100	80–100
ML	95	41	0

Zukowski, 1988). We were interested in determining whether there would be a similar benefit to performance when the units to be combined correspond to syllables within real words. Data from age-matched controls would be relevant to the debate as to whether syllabic units are generally (i.e. in non-brain-damaged populations) functional in reading. The use of this task with ML would provide an opportunity to observe an effect of sublexical structure on the processing of real words and would thereby provide a test of the hypothesis that syllabic units are functional in ML's visual word recognition processes. Compared to the task of blending auditorily presented phonological segments, we view the anagrams task as more directly relevant to the issue of the role of sublexical phonology in reading. If ML's performance benefits from having the fragments to be combined correspond to syllable units, then we would have more evidence that the syllable effects we have observed in reading with this patient are not specific to the processing of nonwords. If control subjects show a similar advantage, we would have evidence that the syllable effect demonstrated by ML does not reflect the pathological operation of a disrupted sublexical route. Although the primary focus in this experiment is on the processing of the syllabic stimuli, onset-body trials were also included.

## ANAGRAMS TASK

### Method

#### Subjects

ML and eight control subjects of about the same age and education level served as subjects in this experiment.

#### Stimuli and Design

Each subject received 288 trials. On each trial the subject was presented with four word fragments and was asked whether the joining of any two of these fragments resulted in a word. Trials requiring a "yes" response were of two types: experimental and control. On *experimental* trials, *syllable* stimuli (two-syllable words) were split at the syllable boundary, whereas *onset-body* stimuli (monosyllabic words with a CCVCC structure) were split at the onset-body boundary. The syllable stimuli had a mean word frequency (Francis & Kučera, 1982) of 53 ( $SD = 114.96$ ), whereas the onset-body stimuli had a mean word frequency of 18.29 ( $SD = 46.24$ ). On *control* trials, words were split so as to violate syllable or onset-body boundaries (see Table 8 for an example of the stimulus materials). Although two of the four fragments could be joined to form a word (target fragments), neither of the other two fragments (distractor fragments) could be combined with any other fragment to form a word. Order and position of the fragments was varied and was matched across the two stimulus types. Distractor fragments were formed by changing one or two letters in a real word and splitting them in a manner similar to the way in which the target word was split. Words were present on 192 of the trials: 48 trials in each of the four conditions outlined above. The other 96 trials required a "no" response and were modelled closely on the "yes" trials. "No" trials were formed by taking an equal number of two-syllable words and monosyllabic words with a CCVCC structure and changing one or two letters to form a nonword. These nonwords were then split at the syllable or onset-body boundary.

TABLE 8  
Sample Stimuli for the Anagrams Task

<i>Stimulus Type</i>		<i>Trial Type</i>	
		<i>Experimental</i>	<i>Control</i>
Syllable	(FABRIC)	FAB TEL GIS RIC	FA STEL GI BRIC
	(CASKET)	TOB PIS CAS KET	STOB PI CA SKET
	(CYNIC)	LE IC CYN SAK	KLE NIC CY SA
Onset–Body	(CRANK)	CR SK BRO ANK	CRA OSK BR NK
	(BLACK)	ONT GR BL ACK	NT GRO BLA CK
	(TRICK)	ALK ICK TR FR	LK CK TRI FRA

## Procedure

Stimulus presentation was controlled by a Macintosh IIcx computer. On each trial subjects were presented with four fragments and were asked whether any two could be joined to form a word. They were instructed to make their decision as quickly and as accurately as possible and to press one of two keys to indicate a “yes” or a “no” response. They were further instructed that if their responses were “yes”, they should indicate the word to the experimenter, who then recorded it. The experiment was run in two separate sessions; items that appeared in the experimental condition in the first session appeared in the control condition in the second session (and vice versa). The two sessions were separated by at least one day.

## Results and Discussion—Error Data

Both the error data and the reaction time data reported here are for the trials containing target words.<sup>3</sup> Table 9 shows the frequency of errors (failures to find the target word) as a function of stimulus condition. In scoring errors, both the initial “yes/ no” response and the correctness of the reported word were taken into account. Mean reaction times are also reported (see later). Due to the yoked nature of the design, an error to one member of an experimental–control pair (e.g. BL ACK vs. BLA CK) necessitated the removal of the other member from the reaction time analysis (this resulted in the loss of 87% of ML’s reaction time data). Thus, the error data tended to be more reliable. Therefore, we will focus on these data.  $2 \times 2$  (stimulus type: onset–body vs. syllable; trial type: control vs. experimental) analyses of variance over items and planned comparisons were conducted on the error data for each subject.<sup>4</sup> As can be seen in Table 9, seven out of eight subjects showed a significant advantage on trials where words were split at the syllable boundary relative to when the split violated the syllable boundary. Whereas seven of the eight control subjects

<sup>3</sup> False-positive responses (i.e. reporting a word where there was none) were extremely rare, comprising fewer than 2% of responses on “no” trials.

<sup>4</sup> We have chosen to use ANOVA to analyse our error data on the grounds that it has been demonstrated that violations of the normality assumption appear to have little effect on the level of significance of the *F*-test (e.g. Glasshouse, Peckham, & Sanders, 1972; Winer, Brown, & Michels, 1991). As reported by Glass et al. (1972), data from Lunney (1970) suggest the robustness of the *F*-statistic even when the dependent variable is dichotomous (see also Cochran, 1950).

TABLE 9  
Mean Number of Errors<sup>a</sup> on the Anagrams Task as a Function of Stimulus Type and Trial Type

Control Subjects	Syllable			Onset-Body		
	Control	Experimental	Difference	Control	Experimental	Difference
MB	18	3	15*	10	2	8*
JC	14	4	10*	2	5	-3
BC	21	18	3	15	11	4
PH	35	18	17*	14	8	6
SM	29	16	13*	19	15	4
LS	24	9	15*	16	8	8
PS	8	2	6*	2	1	1
MW	8	1	7*	2	1	1
Mean	20	9	11*	10	6	4*
Range	8-35	1-18	3-17	2-15	1-15	-3-8
ML	46	24	22*	36	26	10*

<sup>a</sup> Out of a possible 48.

\* Denotes significance at  $p < .05$ .

showed some indication of an advantage on trials where words were split at the onset-body boundary, this difference reached significance for only one individual control subject. The Stimulus Type  $\times$  Condition interaction was significant for subjects JC and PH, reflecting a larger advantage of the experimental trials over the control trials for syllable stimuli than for onset-body stimuli. The interaction approached significance for two other subjects: MW and PS ( $p < .06$ ). (However, see later for a discussion of problems associated with making this comparison.)

The error data from the control subjects were also analysed at a group level using a  $2 \times 2$  analysis of variance with the within-subject factors stimulus type (syllable vs. onset-body) and trial type (control vs. experimental). There was a main effect of stimulus type such that more errors were made to syllable stimuli (mean = 14.5) than to onset-body stimuli (mean = 8),  $F(1, 7) = 18.59, p < .005$ . This difference suggests that the somewhat higher frequency of the syllable stimuli did not aid performance relative to the onset-body stimuli. There was also a main effect of trial type reflecting higher error rates on control trials than on experimental trials (see Table 9),  $F(1, 7) = 26.61, p < .005$ . The difference between the control and experimental trials for the syllable stimuli was significant,  $F(1, 7) = 36.46, p < .005$ , as was the difference for the onset-body stimuli,  $F(1, 7) = 7.22, p < .05$ . Finally, there was a Stimulus Type  $\times$  Trial Type interaction,  $F(1, 7), p < .005$ , indicating a larger benefit of the experimental over the control trials when the units to be combined were syllables than when they were onset-body units. Thus, these data replicate those of Treiman and Chafetz (1987) in that we observed a significant advantage when units to be combined formed onset-body units than when they did not. However, the current results go beyond those of Treiman and Chafetz in that they also indicate an advantage when units to be combined form syllables within



words. Interestingly, the benefit appeared to be greater for syllable units than for onset–body units. However, there is some difficulty in interpreting this difference as there was a much higher level of performance on the control onset–body trials than on the control syllable trials. There are at least two factors that could have contributed to a higher level of performance on the onset–body trials: (a) As there is a relatively limited set of word-initial and word-final consonant clusters, these trials contained units that were repeated within the experiment, and (b) there are phonotactic constraints on which consonant clusters can occur in word-initial or word-final positions (for example, “bl” never occurs in word-final position, whereas “ck” never occurs in word-initial position). Therefore, for the onset–body trials it may have been easier to determine the ordering of units. Although these factors may have contributed to a higher level of performance on onset–body trials and may compromise a comparison of onset–body with syllable performance, they do not compromise the main finding that the control subjects showed a large syllable effect.

ML demonstrated a pattern similar to that of the control subjects (see Table 9): He was more likely to find the target word when the units to be combined were syllables or onsets and bodies than when they were not. For the syllable stimuli, the advantage for the experimental over the control condition was significant,  $t(94) = 6.13$ ,  $p < .01$ , as was the advantage for the onset–body stimuli,  $t(94) = 2.51$ ,  $p < .05$ . The difference between these differences was significant,  $F(1, 94) = 6.56$ ,  $p < .01$ , indicating that ML was more likely to find the target word when the units to be combined were syllables than when they were onset and body units. Thus, as was the case with the segmentation and nonword reading tasks, ML performs at a higher level with syllabic units than with units that do not correspond to syllables within words. Furthermore, the control subjects showed a very similar pattern. However, the advantage for the control subjects (mean difference = 7) was not as large as that for ML (12-item advantage). Furthermore, as can be seen from Table 9, the control subjects performed substantially better than ML on this task.

## Results and Discussion–Reaction Time Data

The reaction time data are presented in Table 10. The pattern of results essentially replicated that of the error data, but was less reliable: For the syllable stimuli, seven out of eight control subjects were faster to find the target word when the units to be combined were syllables than when they were not. However, this difference only reached significance for three of these subjects (see Table 10). For the onset–body stimuli, six out of eight control subjects were faster to find the target word when the units to be combined were onset–body units than when they were not, although this difference only reached significance for two of these subjects (see Table 10). The interaction between stimulus type and trial type failed to reach significance for any individual control subject. Although we did not analyse ML’s reaction time data (due to the large number of missing observations), we computed his mean reaction time (over condition) on correct “yes” responses to be about 17 sec. This indicates that ML was much slower in this task than were the control subjects (see Table 10).

The reaction time data from the control subjects were also analysed at a group level using a  $2 \times 2$  analysis of variance with the within-subject factors stimulus type (syllable vs. onset–body) and trial type (control vs. experimental). There was no main effect of

TABLE 10  
 Mean Reaction Times<sup>a</sup> on the Anagrams Task as a Function of Stimulus Type and Trial Type

Control Subjects	Syllable			Onset–Body		
	Control	Experimental	Difference	Control	Experimental	Difference
MB	11.81	9.27	2.54	11.58	7.58	4.00*
JC	5.81	4.62	1.19	4.11	3.26	0.85
BC	7.56	6.24	1.32	6.97	5.29	1.68
PH	3.48	3.87	−0.39	4.66	4.70	−0.04
SM	3.98	3.34	0.64	2.93	3.15	−0.22
LS	4.36	2.75	1.61*	4.56	3.18	1.38*
PS	3.78	2.79	0.99*	3.16	2.82	0.34
MW	4.28	3.08	1.20*	3.38	3.23	0.15
Mean	5.63	4.50	1.14*	5.17	4.15	1.02

<sup>a</sup> In sec.

\* Denotes significance at  $p < .05$ .

stimulus type,  $F(1, 7) = 2.14$ ,  $p = .19$ , but there was a main effect of trial type such that subjects were 1.08 sec faster to find the target word on experimental trials than on control trials,  $F(1, 7) = 8.16$ ,  $p < .05$ . Finally, the Stimulus Type  $\times$  Trial Type interaction failed to reach significance,  $F < 1$ .

## Summary of Blending Results

In the phonological blending task with auditory presentation, ML was completely unable to blend phonemes, yet had little difficulty blending syllables. ML showed some ability to blend onset and body units, though he performed quite poorly. Control subjects demonstrated little difficulty in performing any of these tasks.

In the anagrams task, ML's performance showed a benefit of having the units to be combined correspond to onset–body units and syllable units. Thus, as was the case with the segmentation and reading tasks, ML's performance on blending tasks also demonstrated a benefit of syllable status.

The pattern of results across the control subjects was quite similar to that shown by ML. Therefore, we have obtained evidence that syllabic representations are more generally involved in visual word recognition—that is, the syllable effect does not appear to represent the pathological operation of a disrupted sublexical route. However, although ML's pattern of performance was similar to that of the control subjects, it should be noted that his overall level of performance never fell within the range of the control subjects. One possible explanation for ML's lower accuracy is that the anagrams task stressed ML's short-term memory (STM) capacity more so than that of the controls. In order to be able to perform this task, it is necessary to be able to retain each segment in memory while it is paired with each of the other segments. As we have indicated previously, ML suffers from a severe STM impairment. Both his word and his nonword span are between two and three items with auditory presentation (see Martin & Lesch, 1996). Furthermore, while ML's phonological retention

appears to be better than his semantic retention, it is clearly not normal. Thus, holding onto multiple segments (segments that are meaningless prior to blending), would be expected to be difficult for ML. This impairment may also explain ML's extremely long reaction times in this task—if ML has difficulty retaining the segments, he may need to rely on the printed stimulus to refresh the phonological trace of the stimulus. This would be assumed to be a time-consuming and difficult process given ML's impairment in nonword reading.

## GENERAL DISCUSSION

We investigated a phonological dyslexic's ability to segment written and auditory stimuli, to read word and nonword stimuli, and to blend auditorily and visually presented sublexical segments to produce a word. ML's pattern of performance on these tasks suggests that his nonword reading impairment is not due to a disruption of the processes subserving sublexical phonology per se, but rather to disruption of some of the representations upon which these processes operate. ML showed difficulty in processing phonemes across all tasks (segmentation, orthographic–phonological conversion, and blending). We observed consistent benefits of syllable status across all tasks and observed relatively little benefit of onset or body status. A comparison of ML's performance with that of matched control subjects argues against the hypothesis that ML's difficulties reflect a global decrement, with the most difficult tasks the most impaired. Furthermore, it does not seem to be the case that the “word-likeness” of the units can explain ML's pattern of performance. ML performs better with the syllabic units than with bodies. It's not clear how body units could be argued to be less “word-like” than syllable units, especially as they would tend to overlap with a larger portion of a real word. Also, performance was better for syllable than for control nonwords even though these items were matched on variables that should reflect “word-likeness”. Based on our results with ML, and the observation of onset, body, and syllable effects in normals, we attribute ML's deficit in nonword reading to the disruption of orthographic and phonological representations at levels below the word and the syllable (i.e. onset, body, and phoneme). However, it should be noted that phonemic and onset–body representations do not seem to have been completely abolished as ML does show a limited ability to process these units. Additionally, ML's processing of syllables, although good, was not perfect. Possibly, ML's processing of syllabic representations suffers somewhat from the lack of support from lower level representations.

We attribute ML's poor nonword reading to a disruption of representations below the level of the syllable. However, the possibility that a blending impairment forms the basis of ML's difficulties in nonword reading merits further comment. Blending impairments are commonly associated with phonological dyslexia (see, e.g. Berndt et al., 1996; Patterson & Marcel, 1992). Furthermore, the pattern demonstrated by ML on blending tasks is somewhat similar to other patients reported in the literature with syllable blending being less affected than phoneme blending (see Berndt et al., 1996). However, our arguments regarding ML's reading impairment are not based solely on the blending results. Across all tasks, ML's performance benefits from having the units correspond to syllables within real words. How would a blending impairment explain ML's differential performance in reading the syllable and control nonwords? Both types of items correspond to segments of

real words and both form syllables (although the control nonwords did not map onto syllables within real words). Additionally, an explanation in terms of a blending impairment presumes that conversion from print to sound is intact. However, ML showed considerable difficulty in producing the sounds corresponding to individual letters. It would also be difficult to explain this pattern in terms of a more generalized phonological deficit (see Farah, Stowe, & Levinson, 1996; Friedman, 1996; Patterson et al. 1996; Sasanuma, Ito, Patterson, & Ito, 1996).

One difficulty with our interpretation regarding preserved syllabic representations for ML is that, as reviewed earlier, the results of studies examining syllabic effects in written word processing have been extremely inconsistent—some studies indicate an effect whereas many others do not. In the current study we have obtained strong evidence from both our patient and from control subjects for the importance of syllabic representations in reading. What is the basis of this inconsistency? One possibility is that, in a fully functioning system (with intact representations at all levels), syllable effects are washed out by effects of other levels of representation. This might provide an explanation for why we observed a syllable effect for ML, but we also observed a syllable effect with control subjects. Interestingly, Balota and Ferraro (1993) have observed an increased incidence of regularization errors in the speeded naming performance of healthy older adults and individuals with senile dementia of the Alzheimer type. Although Balota and Ferraro suggest that the increase in regularization errors is the consequence of a breakdown in the inhibition of output from the assembled route, it would be of interest to ascertain whether these results could be accommodated by a shift, with age, in the units which dominate the assembly process (e.g. a shift from larger to smaller units). That is, perhaps the conversion process characteristic of the older adults in the present study is dominated by different units from those of the younger adults that generally serve as subjects in psychological experiments. A less interesting explanation for the inconsistency of syllable effects is that studies may employ different definitions of the syllable—different linguistic theories locate syllable boundaries differently (see Seidenberg, 1989).

Our results are consistent with the approach taken by Shallice et al. (1983; see also Marcel, 1980). In their model, stored spelling-to-sound correspondences exist for various sizes of orthographic units including graphemes, consonant clusters, subsyllabic units, syllables, and morphemes. According to this view, the visual word-form system (see Warrington & Shallice, 1980) detects letter groups of various sizes and then transmits this information to corresponding units in the phonological system. Spelling-to-sound conversion is assumed to take place at a number of levels in parallel, and although higher levels are assumed to be available more rapidly, they are also assumed to be more sensitive to neurological degeneration. Thus, Shallice et al. (1983; Shallice & McCarthy, 1985) propose that, as a result of brain damage, larger units of correspondence should drop out before lower levels. Their case study of the surface dyslexic patient HTR supports this claim. However, we are suggesting that the pattern of performance that we have observed in our phonological dyslexic patient, ML, is due to the selective impairment of levels of orthographic-phonological representation *below* the level of the syllable (with intact syllabic and whole word representations). Therefore, it would seem that larger units are not necessarily the first to be disrupted as a result of brain damage and that a multiple-levels model can provide an account for *both* surface dyslexia and (at least some instances of) phonological dyslexia.

In Norris' (1994) implementation of Shallice et al.'s (1983) model, different levels of spelling-to-sound correspondence (e.g. phoneme, body, word) are combined in an interactive activation network to produce a pronunciation of the input. In this model there are six levels of orthographic input units: initial consonant clusters, vowels, final consonant clusters, initial cluster plus vowel, vowel plus final cluster (body), and words/ syllables (the syllable level corresponds to the word level when only monosyllabic words are used). There are three sets of output nodes: initial consonant/ cluster, the vowel, and the final consonant/ cluster. As a result of competition among all possible pronunciations at all levels, a single unambiguous pronunciation of the input is produced. Parameters were set by fitting the model to the data of Taraban and McClelland (1987) and Waters and Seidenberg (1985). In simulations of eight experiments (from Andrews, 1989; Brown, 1987; Glushko, 1979; Jared, McRae, & Seidenberg, 1990; Kay & Bishop, 1987; Seidenberg et al., 1984) the model accurately predicts effects of word frequency, regularity, and consistency. Presumably, it would be relatively straightforward to simulate ML's performance—nodes corresponding to subsyllabic representations (which are explicitly represented) would have to be disrupted.

The approach taken by Seidenberg and McClelland (1989) is similar to that of Norris in the sense that there are no distinct mechanisms corresponding to sublexical and lexical phonology. However, the two approaches differ in *how* they represent orthographic-phonological correspondences: Norris' (1994) model represents these correspondences "locally"—that is, there are *individual* nodes that represent different units (e.g. graphemes, morphemes, words). Seidenberg and McClelland's (1989) model, on the other hand, represents the relationship between orthography and phonology in a more distributed fashion. (See Besner, in press, for a discussion of single, dual, and three-route models of reading and for a discussion of localist versus distributed representations.) In their model, the mapping from orthography to phonology is accomplished via a layer of "hidden" units between orthographic input and phonological output layers. During learning, *sets* of nodes become dedicated to certain representations. The hidden units are necessary because with a two-layer network that maps graphemes to phonemes there is no set of weights that will work for all the training patterns. The hidden units serve to "re-represent" the input patterns by distributing activation over sets of units with the result that similarity across input patterns is decreased (see Plaut et al., 1996). It is difficult to see how these hidden units could be damaged to produce ML's pattern of performance. In these models there is no special status afforded to specific levels of representation—the network merely encodes statistical regularities of the language. ML's nonword reading benefited when the units corresponded to syllables within real words relative to when the units formed segments of real words but did not map onto a syllable within real words. This benefit was observed even though the two types of stimuli were matched on a number of variables to which distributed models would be expected to be sensitive: summed frequency of words containing the segment, number of neighbours, and bigram frequency.

We suggest that the representations upon which the assembled route operates should not be thought of as "non-lexical" but rather as "sub-lexical"—that is, derived from lexical items. We propose that an intact reading system contains multiple levels of representation for words that it has previously encountered. When a new word is encountered,

it is parsed and mapped onto every level of representation for which there is a corresponding unit. For ML, whole word and syllabic representations appear to be relatively intact, hence his relatively good reading of words and relatively good reading of nonwords that correspond to syllables within real words. However, when the nonwords to be read are letter sequences that occur within a real word, but do not form a syllable within a real word, ML performs very poorly because lower level mappings (i.e. grapheme-to-phoneme) are not available.

It is interesting to note that more recent implementations of the Seidenberg and McClelland-type model (Plaut et al., 1996), have moved towards incorporating more localist representations. The Plaut et al. model incorporates onset, vowel, and coda (word-final consonant cluster) representations instead of representing phonology through the use of Wickelfeatures (context-sensitive triplets) as in the Seidenberg and McClelland (1989) model. However, the work of converting orthography to phonology is done by the hidden units. The hidden units are necessary in order to decrease similarity across input patterns. However, an alternative strategy suggested by Plaut et al. is for the modeller to specify different levels of input unit (as does Norris, 1994). The current results suggest that this may be the better approach and that the syllable should be represented among those units. As argued earlier, the Norris and Plaut et al. approaches differ primarily in terms of the representation of the units involved in orthographic-phonological conversion. In the approach taken by Norris (see also Shallice et al., 1983), the different levels (i.e. phoneme, onset, body, syllable, word) are represented in such a way that they could be independently affected by brain damage. In the Seidenberg and McClelland (1989) and Plaut et al. approach, the relation between orthography and phonology is represented in a much more distributed fashion—there is no clear separation between different levels of representation. Thus, models incorporating localist representations provide a more ready account of how it is that certain levels of representation can be disrupted while others remain relatively intact (see Patterson & Hodges, 1992). A separate issue is whether either class of model can account for syllable effects. To date, both types of model have been restricted to the processing of monosyllabic words. Thus, whether or not either class of model can accommodate our results must remain an open question until models are constructed to deal with multisyllabic words and until the appropriate simulations are run.

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## APPENDIX

Syllable and Control Nonwords Employed in  
the Reading Tasks

<i>Word-initial Nonwords</i>		<i>Non-initial Nonwords</i>	
<i>Syllable</i>	<i>Control</i>	<i>Syllable</i>	<i>Control</i>
clois	brist	sorb	oist
cres	fict	bort	hage
chol	spee	mous	rame
chis	fost	vert	ront
giz	lup	brate	stent
boun	mout	serk	tomp
pud	mep	ceps	trab
brin	nort	muth	krat
griz	nymp	vorce	fless
frus	misp	voke	terg
meth	dist	crete	droom
cem	fav	fect	blic
bril	flig	rette	welve
clem	dimp	plode	spass
frac	filt	dren	spen
chal	chen	tigue	troke
skel	amph	brupt	kless
treb	dext	boose	twise
cush	balc	phoid	troom
chig	banj	droit	scous
grov	barm	plex	trut
chev	belf	flect	scove
splut	kerch	blem	roup
slov	pral	dral	dway
cler	calc	vage	scue
crev	drud	nence	slead
grum	bulg	pult	slin
clav	rept		
slen	anth		
flut	furb		
breth	freeb		
vod	soj		
bris	canv		
shim	hois		