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11 Sublexical Structures in Visual Word Recognition: Access Units or Orthographic Redundancy?

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ABSTRACT

Several theories assume that words are parsed into sublexical structures such as syllables, morphemes, or BOSSes as part of the recognition process. Empirical evidence for each of these units has been inconsistent; moreover, the notion that such units function as "access" codes is problematic in light of the properties of English orthography. An alternative view is that the effects of such units derive from orthographic redundancy. The present studies used feature integration errors to examine the perceptual groupings of letters in visual word recognition. Experiment 1 showed that syllables rather than BOSSes influenced feature integration errors. Experiment 2 showed that such errors occur when syllables are marked by low-frequency bigrams. Experiment 3 showed that orthographically similar pairs such as NAIVE and WAIVE act alike with respect to feature integration errors. The results suggest that recovering structures such as syllables or BOSSes is not a necessary stage in processing. To the extent that such units emerge, it is because they consist of spelling patterns that are salient in terms of orthographic redundancy. The results are discussed in terms of connectionist models in which there are no parsing mechanisms or access units.

INTRODUCTION

There have been several proposals that complex words are *parsed* or *decomposed* into sublexical units as part of the recognition process. These sublexical units (sometimes termed access units; Taft, 1985) are then used to search lexical memory until an entry is found that corresponds to the input string. Examples of this approach include the Spoehr and Smith (1973) model, in which the access units were assumed to be syllables and the parsing heuristics were based on iterative application of Hansen and Rodgers' (1968) syllabification rules; Taft's (1979a) prefix stripping model, in which the access unit is the stem of a prefixed word, and the parsing heuristics simply strip prefixes to yield stems; and Taft's (1979b) BOSS model, in which the access unit ("BOSS") is defined as "the first part of the stem morpheme of a word, up to and including all consonants following the first vowel, but without creating an illegal consonant cluster in its final position" (Taft, this volume). Examples include LANT in LANTERN and RHUB in RHUBARB.

Within this framework, two issues have arisen. First, what are the sublexical units that mediate lexical access? Pretheoretically it appears that words contain several potential subunits—syllables, morphemes, BOSSes—and it seems unlikely that all would be tried in parallel. Empirical studies have focused on determining which of these is actually used. A second, closely related question concerns the processes by which the relevant units are recovered; here research has focused on identifying parsing heuristics that will yield correct decomposition given the vagaries of written English.

Extensive research has failed to converge on the identity of a unique access unit. Although space limitations preclude a thorough review of this literature, it can be summarised by saying that there is both positive and negative evidence for several different units. For example, Jared and Seidenberg (Note 1) review the experiments on the role of syllables; these studies have yielded remarkably inconsistent results. Similarly, Taft (1979b) provided evidence implicating the BOSS unit, while Lima and Pollatsek (1983) found evidence against the BOSS in one study and for both syllables and BOSSes in another. The latter finding is particularly distressing to the word parsing approach, because it implies that there is no single "access unit." Much of the evidence for morphological units in recognition derives from studies using the repetition priming methodology, which has yielded results of a similar character (see Monsell, 1985; Henderson, 1982; Seidenberg, in press). Other problems with the parsing approach centre on the parsing heuristics themselves; see, for example, the Coltheart (1978) and Henderson (1982) discussions of the Spoehr and Smith model.

Analogous problems have arisen in connection with the role of phonological codes in visual word recognition. The dual-route model (Coltheart, 1978; Forster & Chambers, 1973; Meyer, Schvaneveldt, & Ruddy, 1975) assumes that most words in English can be recognised on the basis of phonological information; spelling-sound correspondence rules are applied to input strings to yield a phonological representation which functions as the access code. The irregularities in the spelling-sound correspondence of English, illustrated by minimal pairs such as GAVE-HAVE, PAID-SAID, and LEAF-DEAF, dictate that even a felicitous set of rules will generate incorrect phonological codes for some words. Thus, a backup mechanism is required for cases where the rules fail; the "direct" visual pathway.

The similarities to word parsing should be clear: Parsing heuristics take

the place of spelling-sound rules, and sublexical units such as syllables or morphemes take the place of phonological codes. As in the case of spelling-sound rules, even a felicitous set of parsing heuristics will fail in a large number of cases, owing to the fact that, like phonology, syllabic and morphological structures are not consistently coded in the orthography. The inconsistencies among syllables are illustrated by minimal pairs such as WAIVE-NAIVE, BAKED-NAKED, and PROVED-PROVEN. The analogous morphological problem is illustrated by prefixed-pseudoprefixed pairs such as REWRITE-REVEAL, DECODE-DELIVER, and DISLIKE-DISPLAY, and compound-pseudocompound pairs such as MANHOLE-MANDATE and SWEETSHOP-SWEETBREAD. As in the dual-route model, there will have to be a backup mechanism to handle the irregular cases (possibly direct access again). The only other alternative is to allow the parsing mechanism to iterate through the rules repeatedly, testing alternative parses until the correct one is selected (as both Spoehr & Smith and Taft have considered). The question which arises is why the processor would bother with this trial-and-error method. Each word can be discriminated from every other word simply on the basis of its component letters. The overhead associated with parsing—which is considerable if reiteration is required—calls into question whether this process would provide any net benefit over simple pattern matching. Other questions concerning this alternative are addressed by Henderson (1982).

The problem in all of these domains lies in the assumption that readers attempt to recover phonological, syllabic, or morphological access codes by applying rules. In all three cases it has been difficult to identify the "correct" set of rules. In all cases, the rules will often fail, requiring backup mechanisms that introduce a high degree of redundancy into the processing system. In all cases there have to be complicated assumptions about the interactions between the two recognition processes which have yet to be worked out. These problems derive from properties of English orthography; phonemes, morphemes, and syllables are represented simultaneously and no one of these types of information can be independently characterised by a set of mapping rules. This makes it difficult to ensure that the processor will recover the correct access code (Seidenberg, in press).

In a writing system such as that for English, then, the notion of an access code is problematical. What would be lost by abandoning this notion entirely? In effect, that is what recent connectionist or parallel processing models of lexical processing do (Kawamoto, Note 3; McClelland & Rumelhart, 1981; Seidenberg & McClelland, Note 4). In these models, there are no levels of representation corresponding to syllables or morphemes.[1] The

[1] The levels aren't there because the models were not intended to apply to complex words. The claim is that this is not a bug; it's a feature.

lexicon embodies the reader's knowledge of the spelling and pronounciation of words, and similarities among words in terms of orthographic and phonological overlap. A word is recognised when the information extracted from the signal, together with the reader's knowledge of the structure of the lexicon, isolates a unique candidate from a range of possibilities. Seidenberg (1985; in press) argues that an approach along these lines will give a unified account of several different aspects of phonology and reading. The conceptual similarities between the problems of recovering phonological information on the one hand, and syllabic and morphological information on the other, suggest that it might be useful to think of the latter in terms of this process as well.

An alternative approach might be developed by considering properties of words that parsing models have tended to ignore. Syllables, for example, are usually defined in terms of rules governing the combination of consonants and vowels (*types* of letters). In the Spoehr and Smith models, for example, letters must be classified as consonants or vowels because the syllabification rules take CV strings into syllables; they do not operate directly on the letter strings themselves. However, the distributional properties of letter patterns in the lexicon (its redundancy) ensure that syllables will tend to be marked by particular letter *tokens*. As Adams (1981) noted, syllable boundaries are often flanked by letter patterns with relatively low transition frequencies. In words such as ANVIL or VODKA, for example, the syllable boundary bisects the lowest frequency bigram in the word. If one plots the frequencies of the component bigrams, the syllable boundary is marked by a dip or trough. These examples are by no means idiosyncractic, as seen by considering some additional cases. Taft (1979b) and Lima and Pollatsek (1983) report experiments on lexical decomposition which employed a total of 93 bisyllabic words. The positional bigram frequencies (Solso & Juel, 1981) for the bigram preceding the syllable boundary, the bigram straddling the syllable boundary, and the bigram following the syllable boundary, averaged across all 93 items, exhibit the trough pattern (the mean frequencies are 790, 559, and 857, respectively). The 80 most frequent bisyllabic words in Kucera and Francis (1967) also exhibit this pattern. Of course, many items deviate from this pattern; nonetheless it represents a general tendency. The trough pattern, then, is a consequence of orthographic redundancy, reflecting the fact that the letters within a syllable co-occur more often than the letters that mark syllable boundaries. This is largely a consequence of the fact that written English is a cipher for speech and there are more constraints on the phonemes that can occur within syllables than between (Seidenberg, in press). The trough pattern represents one consequence of orthographic redundancy; many others could be identified (see Adams, 1981).[2]

[2]This discussion of orthographic redundancy and syllabic structure owes a great deal to Adams (1981).

If the processing system were able to exploit orthographic redundancy, sublexical units such as syllables would influence recognition without parsing or decomposition. Models such as Adams (1979), McClelland and Rumelhart (1981), and Kawamoto (1986) appear to have the potential to make use of this information. Orthographic redundancy reflects facts about the distribution of letters in the lexicon; this information is implicitly coded in the connection structure of the lexical networks in these models. In the McClelland and Rumelhart (1981) model, what are termed "neighbourhood" effects are effects of orthographic redundancy mediated by word-letter interconnections. An interesting hypothesis is that sublexical units are an emergent property of the parallel activation process leading to recognition. According to this view, sublexical units reflect coalitions of letters that have been mutually reinforced during the parallel activation process. Given the facts about the distribution of letter patterns in the lexicon, the parallel activation process will, in general, isolate sublexical coalitions that correspond to such higher-level units. However, it does so merely by exploiting this distributional information; neither syllabic nor morphemic units are directly represented, and there are no parsing routines dedicated to recovering them. This system will not have to retreat to a separate backup mechanism in irregular cases. In a parsing system, these cases are devastating because the primary recognition mechanism requires the recovery of the appropriate access units. In the present account, there are no "access units"; there is simply activation of component letters. Syllabic or morphological irregularities might slow recognition, but would not pose a special problem.

The following experiments were designed to obtain additional empirical evidence bearing on this account. Given the inconsistent results of previous studies, the basic goal was to gain evidence concerning the type(s) of sublexical units that emerge in word recognition and the conditions under which they emerge. A second goal was to explore a new method of investigating effects of sublexical structure. Each of the methods used in previous research has serious limitations. Subjects' strategies for performing lexical decisions are greatly affected by the composition of the stimuli in an experiment (Shulman, Hornak, & Sanders, 1978; Waters & Seidenberg, 1985). Naming latencies may not be sensitive to sublexical structures if subjects begin to initiate their responses before they have completed processing of a word (Henderson, 1985); furthermore they may be affected by factors related to articulation rather than lexical access (Balota & Chumbley, 1985; Landauer & Streeter, 1973). Marking syllable structures through case alternations (e.g., CONtent vs. CONTent) and other manipulations of stimulus characteristics may induce subjects to use units that would otherwise be ignored. Hence it would be useful to have a better method of assessing on-line effects of sublexical structure.

OVERVIEW OF METHODOLOGY

The experiments employed a methodology introduced by Prinzmetal and Millis-Wright (1984; also Prinzmetal, Treiman, & Rho, 1986) which uses feature integration errors (Treisman & Schmidt, 1982) to diagnose perceptual groupings of letters. Treisman and Schmidt tachistoscopically presented stimuli consisting of numbers and letters drawn in different colours. In a variety of tasks, subjects reported incorrect conjunctions of alphanumeric characters and colours at rates greater than expected by chance. Prinzmetal and Millis-Wright (1984) showed that structural properties of letter strings influenced the pattern of feature integration errors. For example, there were more erroneous conjunctions in words and psuedowords than in random letter strings.

Prinzmetal et al. (1986) extended this methodology to examine effects of syllabic structure. Consider a word such as ANVIL printed in two colours, *AN*vil.[3] The word is displayed tachistoscopically for a duration that produces about 10% errors over trials. The subject's task is to report the colour of a target letter, e.g., V. Prinzmetal et al. reasoned that, if subjects recover syllabic units during recognition, they should not tend to respond erroneously with the colour of N, since N and V are in different syllables. That is, the syllable boundary should act as a barrier to feature integration errors. In contrast, if the display were *ANV*il, subjects might tend to report that V was actually the colour of *il*, because VIL forms a syllable. Errors of the first sort, which "crossed" the syllable boundary, will be termed "violation" errors; errors of the second type, which respected the syllable boundary, will be termed "preservation" errors. If syllables influence the pattern of feature integration errors, there should be more preservation errors than violation errors. Prinzmetal et al. (1986) reported five experiments, four of which yielded this pattern, and concluded that syllables are perceptual units in reading. These studies are discussed in greater detail below.

EXPERIMENT 1

The first experiment examined two potential subunits; syllables and BOSSes. Although syllables are familiar units, their theoretical status is unclear (cf. Kahn, Note 2); there are clear cases that all theories of syllable structure treat alike and unclear cases where they differ. For example, what is the syllabic structure of CAMEL? According to Hoard's (1971) syllabification rules, which maximise intrasyllabic consonant strings surrounding a stressed vowel, it is CAM/EL (this is also how it is treated in dictionaries). According to a "maximal syllable onset" principle, proposed frequently in the linguistics

[3]Here and in the remainder of this paper different colours will be represented by different cases. In the experiments, all letters were presented in upper case.

literature (see, e.g., Hansen & Rodgers, 1968; Selkirk, 1980), it is CA/MEL. According to Kahn (Note 2), the M in CAMEL belongs to both syllables. As an alternative to syllables, Taft (1979b) proposed the BOSS (Basic Orthographic Syllabic Structure). Taft was not responding to the fact that syllables are hard to define. Rather, his goal was to define an access code that would be identical for morphologically related words. The syllabification of FASTER, for example, is fas/ter; morphologically, however, it is fast/er. If the access code were the syllable, the recognition process would differ for FAST and FASTER; however, the Taft and Forster (1976) model suggests that morphologically related items are recognised by accessing a common entry in the lexicon. This could be accomplished if the BOSS were the access unit.

As noted earlier, existing evidence concerning both syllables and BOSSes is inconsistent. The feature integration error methodology provides a simple way to contrast these units. Consider the stimulus conditions in Table 11.1. In words where the BOSS is simply one letter longer than the initial syllable, an error that preserves one unit violates the other. When errors are defined in terms of syllable boundaries, the predictions are as follows: If syllables are recovered during prelexical processing, preservation errors should outnumber violation errors; if BOSSes are recovered, violations should outnumber preservations. Experiment 1 examined these alternatives.

TABLE 11.1
Stimulus Conditions, Experiment 1

		Type of Error	
Display	*Target*	*Syllable*	*BOSS*
*BUR*den	D	Violation	Preservation
*BURD*en	D	Preservation	Violation
*PAS*ture	T	Violation	Preservation
*PAST*ure	T	Preservation	Violation

NOTE: Words were presented in upper-case letters in two colours. In all tables, different cases indicate different colours. Violation errors cross the boundary between units; preservation errors occur within the unit.

Method

The experiment was run in two parts. The stimuli in Experiment 1a were 34 words, a random subset of the items from the Taft (1979b) and Lima and Pollatsek (1983) materials. As noted above, these words exhibit the trough pattern. These bisyllabic words were presented in the conditions given in Table 11.1. Because each word was, in effect, tested against itself, the BOSS unit in each word was necessarily one letter longer than the syllable. Experiment 1b was run in order to address this potential confound. The stimuli in Experiment 1b were 15 pairs of words (also from the Taft and Lima & Pollatsek materials); pairs were matched so that the BOSS of one was equal in length to the syllable of the other. In PASTURE, for example, the BOSS is PAST; it was matched with THUNDER, in which the initial syllable, THUN, is also four letters long.

In both experiments, each word was presented in two display conditions. In Experiment 1a, the 34 words × 2 display conditions per item yielded 68 test trials, plus 8 catch trials. Order of stimulus presentation and assignment of colours per trial were randomised for each block of 76 stimuli. Four blocks were presented per subject (N = 13). In Experiment 1b, the 30 words × 2 display conditions per items yielded 60 trials, plus 8 catch trials. Randomisation was as in Experiment 1a. Each subject (N = 12) was presented with 3 blocks.

The procedure closely followed Prinzmetal et al.'s (1986). Each stimulus word was displayed tachistoscopically in two colours, followed by a high-contrast mask. The subject's task was to identify the colour of a target letter designated on each trial. On catch trials, the target letter did not occur in the string. Display durations were set for each subject to produce approximately 10% errors. Errors of the following types could occur: (1) misses (subject incorrectly reports that target letter did not occur in stimulus); (2) false alarms (subject responds with a colour on a catch trial or responds with a colour that was not in the display); (3) feature integration errors (subject responds with the colour of a different letter in the display).

The rates of (1) and (2) errors were very low and these errors were randomly distributed across display conditions in all experiments. Only the last type of error is of theoretical interest; it includes the preservation and violation errors. In the presentation of the results, preservation and violation are defined with respect to the syllable boundary.

Stimuli were presented in large upper-case letters on a Commodore colour monitor controlled by an Apple IIe computer. Stimulus colours were red, blue, green, and white. Each trial began with the presentation of a target letter in the centre of the monitor. After 1.5sec, the target was replaced by a solid white rectangle that covered most of the screen. The stimulus word was then presented for a brief duration in one of the four corners of the screen in order to prevent subjects from focusing on one or two letter positions. It was then replaced again with the white masking rectangle. The subject then indicated by pressing one of five response keys either: (1) the colour of the target letter; or (2) the absence of the target letter from the display (catch trials).

Display durations were calibrated in terms of the number of 16.67msec refresh cycles. These durations were set for each subject during 3 blocks of 30

practice trials. The experimenter adjusted the number of cycles until the subject was making approximately 10% errors overall. Display durations were modified between test blocks to keep the error rate at this level. This procedure was used in all experiments described herein. The mean exposure duration per subject across experiments was 11 refresh cycles (about 183msec), with a range of 7–15 cycles.

Results and Discussion

The overall error rate was 11.2%. Subjects incorrectly reported that a target letter was not present in the stimulus on 0.7% of trials, responded with a colour when the target was not actually present on 0.3% of trials, and responded with a colour that was not in the display on 0.3% of trials. Preservation or violation errors occurred on 11.5% of the trials when the target letter was actually present. Table 11.2 presents the proportions of preservation and violation errors in both versions of the experiment. These proportions represent the number of errors of each type out of the number of trials on which such an error could occur. For both sets of stimuli, there were more preservation errors than violations, indicating that syllabic boundaries affected feature integration errors more than BOSS boundaries. Because of the difference in the number of trials per condition in the two versions, the data were analysed separately. For Experiment 1a, the difference between preservation and violation errors was significant, $t(12) = 2.23$ by subjects and $t(33) = 2.91$ by items, both $P < 0.05$. The same outcome held for Experiment 1b, $t(11) = 4.88$ by subjects and $t(29) = 4.18$ by items, both $P < 0.01$.

TABLE 11.2
Mean Percent Errors, Experiment 1

	Violation	*Preservation*
Experiment 1a	8.0	14.1
Experiment 1b	7.5	17.0

NOTE: Errors are defined in terms of syllables.

The results suggest that syllables rather than BOSSes were utilised during the recognition of these words. The reason why the present results are inconsistent with Taft's (1979b) is unclear, since the stimuli in this experiment were a subset of those he used. Taken with the results of Lima and Pollatsek (1983), which included the same stimuli, it appears that the BOSS is not perceptually salient.

This conclusion is not altered by the results of three additional studies Taft (this volume) interprets as providing further evidence for the BOSS. In each of these studies, three potential units were contrasted: the initial syllable, the BOSS, and the BOSS plus one letter. In the word THUNDER, for example, the units are THUN, THUND, and THUNDE, respectively. The stimuli were presented in ways that emphasised these units. For example, each unit was used as a prime prior to presentation of the complete word. The logic of the experiments was that if the display emphasised a unit that was relevant to processing, responses would be facilitated. The results of the experiments are mixed. In all experiments, the BOSS conditions yielded faster responses than the syllable conditions. As Taft noted, this comparison is confounded with length. In order to conclude that the BOSS is salient, it would also have to differ from the still longer BOSS + 1. However, in none of the experiments is there a reliable difference between BOSS and BOSS + 1. Taft's comparisons involve a complex confounding of length, type of unit, and orthographic redundancy, making if difficult to interpret the results.

EXPERIMENT 2

The second experiment examined the conditions under which syllabic effects emerge. Prinzmetal et al.'s (1986) first three experiments showed that orthotactically marked syllable boundaries affect feature integration errors. The stimuli were words such as ABHOR and ANVIL, in which the bigrams straddling the syllable boundaries (BH, NV) always appear in different syllables in multisyllabic words. That is, there is an orthotactic constraint in written English that dictates that these letters cannot appear within a syllable in a word with two or more syllables. Their fifth experiment showed that syllable boundaries that coincide with morphological boundaries (e.g. LETUP, TODAY) also affect colour errors. Their fourth experiment examined words in which the syllable boundary was marked in neither of these ways (e.g. CAMEL, SALAD). Prinzmetal et al. considered these syllables to be phonologically defined. Because the syllable boundaries in these words failed to affect colour errors, they concluded that syllables are only used when they are orthotactically or morphologically marked. These results present a problem for simple word parsing schemes that search for syllables defined in terms of CV structures (e.g. Smith & Spoehr, 1974), because they do not consider orthotactic or morphological factors.

There may be another explanation for Prinzmetal et al.'s (1986) failure to obtain syllabic effects in this experiment, however. The items in the experiments that yielded syllabic effects exhibited the trough pattern around the syllable boundary. The stimuli in the experiment that failed to yield a syllabic effect did not. The latter included 5-letter words with the syllable boundary either after letter 2 (e.g. LA/PEL, "2/3 " items) or after letter 3 (e.g., CAM/EL, "3/2" items). There were 12 words of each type. Mean positional bigram frequencies were calculated (from Solso & Juel, 1981) for the bigrams preceding, straddling, and following the syllable boundary. For the 2/3 words, the mean bigram frequencies were 815 (preceding), 352 (straddling), and 348 (following); for 3/2 words, they were 797, 684, and 685, respectively. Hence, the results are consistent with the generalisation that the frequencies of the letter patterns determine "syllabic" effects; neither orthotactic nor morphological factors need to be invoked. This generalisation is consistent with the results of Experiment 1, in which the stimuli also exhibited the trough pattern around the syllable boundary.[4]

These observations led to Experiment 2, a replication of Prinzmetal et al.'s Experiment 4 with some modifications. As in their experiment, the stimuli were bisyllabic words with "phonologically" defined syllables. The syllable boundary did not correspond to a morpheme boundary and the bigrams straddling the syllable boundary were not of the orthotactically constrained type. The stimuli had the same CV structure as their words. However, in contrast to their materials, all of the items exhibit the trough pattern. Twelve of these words were taken from Prinzmetal et al.'s stimuli, and 12 new items were added. If these items exhibited syllabic effects, it would indicate that the failure to obtain these effects in Prinzmetal et al.'s experiment was not due to the fact that their syllables lacked orthotactic or morphological cues; rather it was because they were not marked by the transition frequencies of the component letters.

Method

The stimuli were 24 bisyllabic 5-letter words, 12 with the dictionary-defined syllable boundary after letter 2 (e.g. LAPEL), and 12 with the boundary after letter 3 (e.g. SONIC). All words had the structure CVCVC; hence none of the bigrams straddling the syllable boundary were of the graphotactically constrained type. All words exhibited the trough pattern around their respective syllable boundaries.

The procedure closely followed that in Experiment 1. Each stimulus word was displayed tachistoscopically in two colours (Table 11.3). The subject's task was to identify the colour of a target letter designated on each trial. The target letter was always the third in the five-letter string. On catch trials, the target letter did not occur in the string. Display durations were again set for each subject to produce approximately 10% errors.

The 24 items × 4 display conditions per item yielded 96 test trials, plus 8 catch trials. The order of stimulus presentation and the assignment of specific

[4] It is interesting to note that many of the stimuli in Prinzmetal et al.'s experiment were items, such as CAMEL, for which the syllabic structure is theoretically unclear.

TABLE 11.3
Stimulus Conditions, Experiment 2

Display	*Target*	*Type of Error*
*LA*pel	P	Violation
*LAP*el	P	Preservation
*VIG*or	G	Violation
*VI*gor	G	Preservation

colours were randomised for each block of 104 stimuli. Four blocks were presented per subject (N = 18). Stimulus presentation was as in Experiment 1.

Results and Discussion

The overall error rate was 10.9%. Subjects incorrectly reported that a target letter was not present in the stimulus on 0.9% of trials, responded with a colour when the target was not actually present on 0.3% of trials, and responded with a colour that was not in the display on 0.8% of trials. Preservation or violation errors occurred on 9.6% of the trials when the target letter was actually present. Table 11.4 presents the distribution of these errors by stimulus condition. The results indicate that subjects made more preservation errors than violation for both 2/3 and 3/2 words. This difference was significant, $F(1,34) = 18.29$ by subjects $P < 0.05$, and approached significance by items, and $F(1,94) = 3.11$ by items, $0.05 < P < 0.10$. The effect of word type and the interaction were not significant in either analysis. Syllabic effects appeared slightly larger for the 3/2 items than for the 2/3 items, which Prinzmetal et al. (1986) also observed.

The results indicate that the presence of neither an orthotactically constrained bigram nor a morpheme boundary is necessary in order to produce

TABLE 11.4
Mean Percent Errors, Experiment 2

Display Type	*Error Type*	*Percent Errors*
3/2 Words		
*VIG*or	Violation	7.9
*VI*gor	Preservation	12.8
2/3 Words		
*LA*pel	Violation	7.4
*LAP*el	Preservation	10.2

syllabic effects on illusory feature conjunctions. Moreover, the stimuli in the present study and in Prinzmetal et al.'s were similar in terms of CV structure, and hence would be treated similarly by syllabification rules. However, the stimuli in the present experiment were marked by the trough pattern, while Prinzmetal et al.'s were not. Hence it appears that presence of these orthographic cues is necessary in order to produce syllabic effects.

There is another piece of evidence consistent with this conclusion. Prinzmetal et al. failed to obtain a syllabic effect in one other condition. Their fifth experiment included nonwords such as XETUH derived from words such as LETUP. Although the words showed the pattern of errors associated with syllabification, the nonwords did not. As in this example, the nonwords were created by replacing the first and last letters of the word stimuli with letters that created very low-frequency bigrams. The effect of this manipulation is to eliminate the trough pattern, consistent with the failure to obtain an effect of syllabic structure. The result indicates that it is not simply the presence of a lower frequency bigram at the syllable boundary that is critical; rather, it is the frequencies of the series of bigrams which create the trough pattern.

EXPERIMENT 3

The third experiment examined pairs such as NAIVE and WAIVE, which are orthographically similar but differ in terms of syllables. If feature integration errors are influenced by syllabic structure, the two types of words should differ, with only the bisyllabic items producing more preservation errors than violation. If the errors merely reflect the grouping of sublexical coalitions of letters, the two types should act alike.

Method

The stimuli were 15 pairs like NAIVE/WAIVE. Other examples include CREATED/PLEATED, NAKED/BAKED, FLUID/FRUIT, and PROVEN/PROVED. Pairs were matched in length (4–8 letters) and the letters that differed did not adjoin the syllable boundary. The display conditions were analogous to those in Experiment 1. Each word contained two colours; the target letter was the item before or after the syllable boundary (or the same letter in a nonsyllabified word). Violation errors occurred when subjects incorrectly responded with the colour of a letter in the adjoining syllable (or the comparable letter in a nonsyllabified word); preservation errors occurred when they incorrectly responded with the colour of the other letters in the target's syllable (or the comparable letter in a nonsyllabified word). An example of the stimulus conditions follows: display = NA*ive*; target = I; error = violation; display = NAI*ve*; target = I; error = preservation; display = WA*ive*; target = I; error = "violation"; display = WAI*ve*; target = I, error = "preservation". The 30 items × 2 display conditions per item yielded 60 test trials, plus 12 catch trials. The order of stimulus presentation and the assignment of specific colours were randomised for each block of 72 stimuli. Six blocks were presented per subject (N = 31). Display durations were set as in the previous experiment.

Results and Discussion

The overall error rate was 10.3%. Subjects incorrectly reported that a target letter was not present in the stimulus on 0.4% of trials, responded with a colour when the target was not actually present on 0.2% of trials, and responded with a colour that was not in the display on 0.5% of trials. Preservation or violation errors occured on 11.0% of the trials when the target letter was actually present.

Results are presented in Table 11.5. The two types of words produced similar results even though only one type contained a syllable boundary. The pattern of results, more preservation errors than violation, is similar to that in the previous experiments. The main effect of type of error was significant by subjects, $F(1,30) = 13.92$, $P < 0.01$, and approached significance by items, $F(1,28) = 2.65$, $0.05 < P < 0.10$. The main effect of word type and the interaction were not significant in either analysis. A difference score (violation errors-preservation errors) was calculated for each word, and the correlation between the two types of words on this measure was 0.68 ($P < 0.05$). Hence the pairs of words tended to act alike with respect to the pattern of errors.

The primary result of this experiment is that words that are orthographically matched acted similarly in regard to perceptual grouping of letters. Hence it was the orthographic properties of the words, rather than their

TABLE 11.5
Mean Percent Errors, Experiment 3

Display	*Error Type*	*Percent Errors*
Bisyllabic Words		
*NA*ive	Violation	10.2
*NAI*ve	Preservation	13.0
Monosyllabic Words		
*WA*ive	"Violation"	8.8
*WAI*ve	"Preservation"	12.2

syllabic structure, that affected subject errors. A second finding is that there were more preservation errors than violation errors. These effects were smaller than in previous experiments and they were significant by subjects but not by items. The absence of a significant effect by items indicates that only some words produced more violation errors. These errors did not depend on whether the stimuli actually contained a syllable boundary or not.

GENERAL DISCUSSION

The results of these experiments, taken with Prinzmetal et al.'s, are consistent with the hypothesis that perceptual groupings of letters in visual word recognition are due to orthographic redundancy. Several considerations point to this conclusion. The trough pattern is the modal profile for bisyllabic words. The experiments which yielded syllabic effects (Prinzmetal et al.'s; our Experiment 1) used stimuli that fit this profile. The experiment that failed to obtain syllabic effects (their Experiment 4) used stimuli that did not fit this modal pattern. When that experiment was replicated using syllables with the same CV structure as in the earlier experiment, but exhibiting the trough pattern, syllabic effects were obtained (our Experiment 2). Finally, words that are similar in terms of orthography act alike with respect to feature integration errors, despite differences in number of syllables (our Experiment 3).

All of these results point to a theory in which the emergence of sublexical units in early decoding depends on the orthographic properties of words. The results are not easy to reconcile with the view that multisyllabic words are recognised by recovering their underlying syllabic structure, which provides an access unit used to search lexical memory. It appears that some words are correctly syllabified; others are syllabified incorrectly (our Experiment 3) or not syllabified at all (Prinzmetal et al.'s Experiment 4). Hence, recovering the correct syllabic structure cannot be a necessary stage in lexical access. The results are more consistent with a theory in which coalitions of letters emerge to the extent that they are marked in the orthography. These coalitions typically correspond to units such as syllables; however, nonsyllabic units that exhibit the right kind of orthographic structure will sometimes emerge and syllables will not emerge when spelling patterns have the properties of monosyllables. These graded effects of sublexical organisation obtain because the coalitions are simply a secondary consequence of parallel activation processes. The system exploits orthographic redundancy because it is encoded in the connection structure of the lexicon but is not obliged to recover the correct syllabification.

I have focused on syllables in this paper, but it should be clear that the same principles may account for the effects of other structures such as morphemes or subsyllabic onset/rime units (Treiman, this volume). Consider a morphologically based parsing strategy such as prefix stripping. Prefixes tend to be highly salient in terms of orthographic redundancy; they are very high-frequency spelling patterns that recur in many words. The bigrams within a prefix will be higher, on average, than the bigrams straddling the boundary between prefix and stem. Hence, prefixes should tend to act as processing units because of their orthographic properties, not because they are morphemes. Similarly, the onset and rime units derive from properties of speech (i.e. closing and opening gestures of the vocal tract). These properties will tend to be reflected in an alphabetic orthography. Clearly, the view I have proposed suggests that it should be possible to derive the effects of these units from strictly orthographic factors. This view would be shown to be incorrect if it were the case that, unlike syllables, other units affect processing whether they are marked by orthographic redundancy or not.

The main limitation of the account I have offered is that there is no specification of exactly which aspects of orthographic redundancy are relevant to processing. The reason for this is obvious: Orthographic redundancy reflects a complex set of facts about the distribution of letter patterns in the lexicon; measures such as bigram frequency, the frequency of a series of bigrams, or positional letter frequency capture very little of this structure. This is perhaps a case in which computational modelling provides a useful alternative to traditional experimental approaches. Instead of deriving statistics that summarise aspects of orthographic redundancy, we can simulate the structure of the lexicon itself. J. L. McClelland and I have recently developed a connectionist model of visual word recognition (Seidenberg & McClelland, Note 4). The model consists of a network of units that encode facts about orthographic redundancy and orthographic-phonological correspondences. This information is carried by the weights on the connections between units. Weights are set during a learning phase in which the model is effectively discovering the structure of the lexicon based on experience. It would be difficult to characterise this connection structure in terms of measures analogous to bigram frequences. However, what the model provides instead is very detailed information concerning the *effects* of this structure; specifically, one can derive measures concerning the relative activation of individual letters and letter patterns. My hope is that this measure will prove to be related to empirical phenomena of the sort considered in the experiments detailed in this chapter.

Exploration of the model is only in its initial stages. However, a number of suggestive results have already been obtained. The model was developed in order to account for facts about the role of orthographic redundancy and orthographic-phonological correspondences in the processing of monosyllabic words, which it does quite well. However, these factors also account for effects of syllabic structure on tasks such as lexical decision, naming, and colour identification. The model takes letter strings as inputs and yields two types of output: A pattern of activation across the phonological output nodes (a phonological code) and a recreation of the input letter string across the orthographic nodes (an orthographic code). In general, naming responses depend on the former, lexical decisions on the latter. The model was tested on the stimuli from Experiment 3. The WAIVE and NAIVE types of words produced similar orthographic output. However, when naming was simulated, the two conditions differed. The bisyllabic words are more difficult to pronounce, because they contain two vowels, and vowels are a source of ambiguity in terms of orthographic-phonological correspondences. Jared and Seidenberg (Note 1) provide behavioural evidence consistent with the model. Lexical decision latencies for these types of words do not differ. Thus, lexical decisions are based on the results of orthographic processing; because the words are similar in terms of orthographic redundancy, they yield similar decision latencies. However, the two types of words produce different results on naming, with the bisyllabic words yielding longer latencies.

The model was also tested on pairs such as BLEACH-BLAZER. Like the WAIVE-NAIVE pairs, the BLEACH-BLAZER pairs differ in terms of orthographic-phonological correspondences; the bisyllabic items contain two vowels, each of which can be pronounced several ways, while the monosyllabic words only have one. Hence, when naming is simulated, the BLAZER-types of words are more difficult to pronounce than the BLEACH-types. In contrast to the WAIVE-NAIVE items, however, the words also differ in terms of orthographic redundancy. BLEACH, for example, contains higher-frequency spelling patterns and has more neighbours (Glushko, 1979) than BLAZER. Hence, the BLAZER types produce poorer orthographic output than the BLEACH types. Consistent with these outcomes, Jared and Seidenberg (Note 1) found that for human subjects, the BLAZER type of words produce longer latencies than the BLEACH type on both naming and lexical decision.

In sum, the effects of syllabic structure on recognition are simulated by a model which only encodes facts about orthographic redundancy and orthographic-phonological regularities. Syllables are not directly represented and there is no parsing mechanism. Because the model encodes orthographic redundancy directly, it provides an alternative to summary statistics such as bigram frequencies. Hence it may provide the basis for a more subtle account of the effects of word structure on processing.

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