How to See a Reading Unit

WILLIAM PRINZMETAL
Princeton University

REBECCA TREIMAN
Wayne State University

AND

SUSAN H. RHO
Princeton University

When briefly presented with a string of colored letters, subjects sometimes report seeing letters and colors in incorrect combinations. We asked whether these illusory conjunctions of letter shape and identity can illuminate the units of analysis that are used by the visual system in word perception. Specifically, are illusory conjunctions more likely between letters within the same syllable of a word than between letters within different syllables? The results of five experiments show that when syllables are defined by orthographic constraints or by morphological boundaries, syllables are functional units in the visual analysis of words and word-like stimuli. Syllables defined by purely phonological criteria do not affect feature integration. We propose that illusory conjunctions can reveal the units of analysis in word perception. © 1986 Academic Press, Inc

The purpose of this study is to test a method for determining the units of analysis used by the visual system in word perception. Efforts to determine these units have had a long history. Huey (1908) commented, on the basis of introspective evidence:

So reading is now by letters, now by groups of letters or by syllables, now by word-wholes, all in the same sentence sometimes, or even in the same word, as the reader may quickly attain his purpose. (p. 81)

Recent proposals for multiple letter units within words have included letters or letter clusters that stand for single phonemes (e.g., SH, AI; Gibson, Pick, Osser, & Hammond, 1962), syllables (Spoehr & Smith, 1973), and morphemes (Chomsky, 1970). As Huey pointed out, these proposals need not be mutually exclusive. The “morphophonemic” nature of English spelling (Venezky, 1967) suggests that readers could be sensitive to both morphological and phonological units. Furthermore, units of analysis could be hierarchically arranged so that, for example, syllables are created by certain combinations of subunits (Fudge, 1969; Mackay, 1972, 1983). Finally, as discussed below, different processes in reading or different reading-related tasks could involve different units. The purpose of this study is, first, to test a new method for determining units in word perception, and

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second, to explore the nature of these units.

The method uses the phenomenon of "illusory conjunctions" of the stimulus features of color and letter shape. This phenomenon was first described by Treisman and Schmidt (1982). When subjects are briefly presented a string of colored letters, they report the colors and letters in incorrect combinations more often than expected by chance. These incorrect combinations are illusory in that they can be phenomenally indistinguishable from veridical perceptions.

Previous research has demonstrated that perceptual organization affects feature integration. For example, Prinzmetal (1981) found that conjunction errors between features in the same perceptual group or unit were more likely than between features in different groups, where groups were defined by Gestalt principles. This result has recently been extended to perceptual organizations that are determined not by stimulus factors, such as proximity grouping, but rather by the subject. Prinzmetal, Gross, and Rho (1986) presented subjects with letter matrices that could be subjectively organized into columns or into rows. When subjects organized the stimuli by rows, conjunction errors of colors and letters were more likely within rows than within columns. When subjects organized the stimuli by columns, conjunction errors within columns predominated. Prinzmetal et al. (1986) proposed that illusory conjunctions represent the visual system's attempt to fill in missing information within a perceptual unit.

The above results suggest that visual features can be constrained by organization imposed on the stimulus by the observer. If linguistically derived "perceptual units" behave like the subjectively derived units in Prinzmetal et al. (1986), then studies of illusory conjunctions could shed light on the units in word perception.

Prinzmetal and Millis-Wright (1984) provided some preliminary evidence that linguistic structure affects feature integration. In their study, subjects were briefly presented three-letter monosyllabic words (e.g., AGE) or nonwords (e.g., VGH) composed of differently colored letters. The task was to report the color of a target letter. Subjects made more conjunction errors with words than with nonwords. Apparently, the visual system processes a short familiar monosyllabic word as a single perceptual unit, or at least by units larger than a single letter. In contrast, a nonword is processed letter by letter. Colors are less constrained when they appear within a single perceptual unit (i.e., a word).

Prinzmetal and Millis-Wright (1984) did not examine the nature of units within a word. The present study asks whether illusory conjunctions can illuminate these units. Specifically, we hypothesize that incorrect combinations of color and letter shape will be more likely within a unit of a word than across units, just as illusory conjunctions within a subjectively defined row of letters are more likely than between rows of letters (Prinzmetal et al., 1986). For example, if the word MAYBE contains the units MAY and BE, a subject should be more likely to report the Y as the color of the M or A than the B or E.

It is not clear, a priori, which intraword units (e.g. letter clusters, syllables, morphemes), if any, will affect the pattern of illusory conjunctions. We decided to begin by looking for an effect of syllables. This decision was made because previous studies using other techniques suggest that syllables can constitute perceptual units. For example, Spoehr and Smith (1973) found that tachistoscopic report accuracy for single letters in a forced-choice task was higher for one-syllable words than for two-syllable words. They interpreted this result to mean that two-syllable words require more processing capacity than one-syllable words. However, the result held only under conditions that might encourage phonological encoding (Spoehr, 1978). Spe-
cifically, the syllable effect was only obtained when a pattern mask was used and when the forced-choice alternatives were presented after the stimulus. Presumably, the pattern mask is destructive to a visual code, and a phonological code is less susceptible to memory decay with delayed presentation of the response alternatives.

Additional evidence for the role of syllables comes from lexical decision experiments. Taft and Forster (1975, 1976) found that decisions to pseudowords were faster if the first syllable was a nonword (e.g., TROWBREAK) than if the first syllable was a word (e.g., FOOTMILGE). They concluded that the first syllable in a polysyllabic word is used to access the lexicon. Finally, Lima and Pollatsek (1983) showed that lexical decisions can be primed by presentation of the first syllable of the target word. Phonologically, morphologically, and orthographically defined syllables were all effective primes in this study.

In order to compare the present method for investigating perceptual units with previous methods, it is useful to consider the ways in which syllable units could be involved in word recognition. Consider the lexical decision task as a model of the processes in word perception. In this task, subjects are thought to form a mental representation of the stimulus, which they attempt to match with an item in the lexicon. The representation could be in terms of a visual code, a phonological code, or both (Coltheart, 1978). It is easy to understand how phonological codes could be structured in terms of syllable units (see, for example, Spoehr, 1981), but visual codes could also be structured by syllables. This possibility is based on the fact that orthographic constraints operate within syllables, not between syllables (Haber & Haber, 1983; Taft, 1979). For example, some consonant clusters can be syllable-final but not syllable-initial (e.g., LK), while others can only be syllable-initial (e.g., SC; see Gibson et al., 1962). Such orthographic knowledge could be used to parse a string of letters into syllable-like units. Spoehr and Smith (1973) suggest that their results reflect phonological encoding, while Taft and Forster (1975, 1976) interpret their effect to reflect the use of syllables for lexical access. Lima and Pollatsek's (1983) syllable priming effects in the lexical decision task may result from the preactivation of lexical codes. The present method does not encourage phonological encoding and lexical access is not required. If syllable effects are found, this may reflect the structure of a prelexical visual code. Alternatively, it may be that subjects derive meaning from the words even though they are not required to do so, and that syllables are involved in lexical access.

Experiment 1 tests whether syllables affect the pattern of conjunction errors. The remaining experiments explore whether the syllable effect is due to phonological, morphological, or orthographic factors.

**Experiment 1**

The first experiment investigated whether syllables, defined by overlapping criteria, are treated as perceptual units by the visual system. The stimuli included five-letter words with a syllable break after the second letter (e.g., EXCEL) or after the third letter (e.g., LOWLY). The syllable boundaries reflected two different criteria. The first was orthographic. In most of the words, the consonant letters on either side of the syllable boundary could not be part of the same English syllable (Haber & Haber, 1983). The second criterion was morphological. Many of the words contained a morphological boundary that coincided with the orthographic boundary. We also tested pseudowords that were created by replacing the middle letter in each of the words with an orthographically possible letter (e.g., EXWEL & LOXLY). The subject's task was to indicate whether a predesignated target letter appeared in the stimulus, and if it did, to indicate its color. The target, when present, was always the
middle letter in the string. If subjects treat syllables as units, they should be more likely to report the target as the color of a letter in the same syllable than the color of a letter in a different syllable.

Method

Procedure. Each trial began with the presentation of a white target letter in the center of a color monitor. After 1.5 s, the target was replaced by a solid white rectangle that covered most of the screen. The stimulus string (five colored letters) was briefly presented and then replaced again with the solid white rectangle. The subject then indicated, by pressing an appropriate button, whether the target letter was present, and if it was present, the target's color. There were five buttons arranged in a row. The first four buttons were labeled with color names (PINK, GREEN, BLUE, YELLOW) and were to be used when the subject thought that the target was present. The fifth button was labeled NO and was used to indicate that the target was absent.

Each subject received three blocks of 30 trials per block for practice. This was followed by six 108-trial blocks on which data were collected. The exposure duration was adjusted individually for each subject between blocks to maintain an error rate of approximately 10%. The mean exposure duration was 14 refresh cycles at 60 Hz (233 ms) and the range was 9 to 25 cycles. Subjects were given the following feedback. If, on a target-present trial, they responded with an incorrect color, subjects were informed by a single brief tone from the computer. If subjects made a letter error, either by responding with a color on a target-absent trial (false alarm), or by responding NO on a target-present trial (miss), the computer sounded four brief tones.

Stimuli. Twelve five-letter words and twelve orthographically legal pseudowords were used. The pseudowords were created by replacing the middle letter in each of the words. Half the stimuli of each type had a syllable break after the third letter and half had a break after the second letter. The stimuli are listed in the Appendix. In each block of 108 trials, 96 trials were target-present trials and 12 were target-absent trials. In each stimulus, all the letters but one were the same color. In a block of trials, each word and pseudoword appeared four times with the target present. The odd colored letter was the first, second, fourth or fifth letter. The target letter, when present, was always the middle letter of the string. Subjects were not informed that the target would always be the middle letter in the string, but they were told that the target would be absent in approximately 10% of the trials. The 108 stimuli were presented in a different random order on each block.

The stimuli were presented on a Heath–Zenith 13-in. color monitor (Model 13-PF-5) controlled by an Apple 2+ computer. Ambient light was from fluorescent ceiling lights. Subjects viewed the displays from a distance of 244 cm. Each of the letters subtended a visual angle of 0.3 degree vertically and 0.26 degree horizontally. The stimulus string was located in one of the four corners of an imaginary rectangle and the distance from the center of the monitor to the center of the string was 0.90 degree of visual angle. Two colors and the stimulus position were selected randomly on each trial. The colors matched Munsell values 10P 8/6 (Pink), 5BG 8/4 (Green), 5PB 6/10 (Blue), and 2.5Y 8.5/6 (Yellow).

Subjects. Twelve subjects, recruited among graduate and undergraduate students at Princeton University, were paid $3.00 for their participation in the 1-h session. The subjects in this and subsequent experiments were approximately evenly divided between males and females, and they did not know the purpose of the experiment. All were native English speakers with normal or corrected-to-normal visual acuity and with no known deficiencies in color vision.
Results

Figure 1 shows the distribution of errors when subjects reported that the target was the color of one of the nontarget items on target-present trials. It is apparent that subjects were more likely to report that the target was the color of an adjacent letter than a nonadjacent letter. This result is consistent with previous evidence that conjunction errors tend to occur between adjacent items (Prinzmetal & Millis-Wright, 1984; Snyder, 1972; Wolford & Shum, 1980). Importantly, subjects were more likely to report that the target was the color of a letter in the same syllable than a letter in a different syllable. When the odd colored letter was in the same syllable as the target, subjects mistakenly reported its color on 6.25% of the target-present trials. The rate was 3.85% for letters in different syllables. The difference was significant in a combined analysis over subjects and stimulus material, min $F'(1,30) = 9.01$, $p < .01$.

The syllable effect did not significantly interact with any other variable in separate analyses over subjects or stimulus material. The syllable effect was as strong for pseudowords as for words. Subjects seemed more likely to make a conjunction error when the syllable break followed the third letter than when it followed the second letter. This effect was significant in the analysis with subjects as the random factor, $F(1,11) = 9.14$, $p < .05$; but it was not significant in the analysis with stimuli as the random factor, $F(1,11) = 2.72$.

Finally, subjects reported a color that was not in the display on 1.9% of the trials and they incorrectly reported the letter on 2.7% of the trials (misses and false alarms). These percentages are based on all the trials, including both target-present and target-absent trials. These few errors did not vary systematically as a function of any of the variables in this experiment.

Discussion

The results of Experiment 1 were straightforward. Subjects reported the target in the color of a letter in the same syllable almost twice as often as they reported it in the color of a letter in a different syllable. This result held for pseudowords as well as for words. The phenomenal experience of the subjects, which is not completely revealed in the data, is also informative. Almost all subjects reported that on some trials they clearly saw two letters in one color and three letters in another color. On other trials, they reported seeing all five letters in the same color. This color spreading is quite convincing. It disconcertingly occurs with the authors, who know quite well that four letters are supposed to be one color and the fifth another. The data show that colors spread within syllables more often than between syllables.

When debriefing our subjects, it also became clear that they generally had no idea of the purpose of the experiment. When told that the hypothesis was that they would be more likely to report the target as a color in the same syllable, most subjects stated that they were uninfluenced by the syllable boundaries. Indeed, many subjects
reported that they did not even read the words. In fact, 11 of the 12 subjects were more likely to report the target as the color of a letter in the same syllable.

Our results may seem puzzling in the following regard. We pointed out that Spoehr (1978) found letter recognition to be better in one-syllable words than in two-syllable words only when conditions favored phonological encoding. None of the factors that favored phonological encoding were present in Experiment 1, and yet we obtained a syllable effect. However, the influence of the number of syllables may have been minimized in the experimental design of Spoehr and Smith (1973; Spoehr, 1978). As a number of syllables increases in words of a fixed length, the size of each unit decreases. Kahneman and Henik (1981) demonstrated in letter recognition and whole report tasks that performance can vary as a function of both the number of units to be processed and the number of items within each unit. The confounding of the number of syllables and the size of each syllable may have reduced the syllable effect for Spoehr and Smith (1973).

Experiment 1 shows that syllables, defined by overlapping criteria, can serve as perceptual units. The remaining experiments attempt to clarify the nature of these visible syllables and also begin to specify the processes that are reflected in our results. In Experiment 2, we ask whether illusory conjunctions are affected by syllables defined by orthographic or phonological criteria, rather than morphological boundaries.

**EXPERIMENT 2**

**Method**

Ten words with a syllable break after the second letter and 10 words with a syllable break after the third letter were used. The former words were all VCCVC’s and latter words were CVCCV’s (C = consonant, V = vowel). The syllable break always came between the two consonants in the medial cluster. The items were selected so that the two consonants in the cluster are rarely part of the same syllable (Haber & Haber, 1983). For example, N and V as in ANVIL do not occur as syllable-initial or syllable-final letter clusters, nor do D and K in VODKA. The words were monomorphic. The stimuli are listed in the Appendix.

The procedure was the same as that of Experiment 1 with the following minor exceptions. There were 90 trials in a block, 80 target-present trials and 10 target-absent trials. The 80 target-present trials resulted from each of the 20 stimulus words appearing four times, once with the odd colored letter as the first, second, fourth, and fifth letter in the string. The mean exposure duration was 15 refresh cycles at 60 Hz (250 ms) and ranged from 7 to 22 cycles. Twelve subjects, recruited as before, participated.

**Results and Discussion**

The results from the target-present trials where subjects responded with a color of a nontarget letter are shown in Fig. 2. As in Experiment 1, subjects were more likely to respond with the color of an item adjacent to the target than with the color of a nonadjacent item. More importantly, orthographic or phonological syllable structure affected performance. When the odd colored letter was in the same syllable as the target, subjects incorrectly responded with that color on 6.4% of the target-present trials. When the odd colored letter was in a

![Fig. 2. For Experiment 2, the percentage of trials on which subjects incorrectly responded that the target letter (i.e., the third letter) was the color of the first, second, fourth, and fifth letter in the string for the following stimulus types: (a) words with a syllable break after the third letter; (b) words with a syllable break after the second letter.](image-url)
different syllable, subjects responded with it on 4.3% of the target-present trials. This difference was reliable, min $F'(1,28) = 5.62, p < .05$. One interaction appeared to be significant. As shown in Fig. 2, the syllable effect seemed to be greater with words with a syllable break after the third letter than the second letter. This interaction was reliable with stimulus material as the random factor, $F(1,18) = 5.35, p < .05$, but it failed to reach significance with subjects as the random factor, $F(1,11) = 3.93, p = .073$ (min $F'(1,24) = 2.27$). The possible significance of this apparent interaction will be discussed later.

The only other errors in the experiment were that subjects responded with a color that was not present in the display on 2.6% of the trials and they committed letter errors on 1.2% of the trials (total misses and false alarms). These percentages are based on both target-present and target-absent trials.

The results appear to show that morphological boundaries are not necessary for a syllable effect to emerge. A potential problem with this conclusion is that several of the items, like INFER, contained strings that are sometimes morphemes (e.g., IN). However, the meanings of these words cannot be generated from morphemic analysis (Henderson, Wallis, & Knight, 1984). Furthermore, a careful examination of the data shows that such “pseudomorphemes” cannot explain the results. The few questionable items all had syllable breaks after the second letter (e.g., INLET, ENROL), but the syllable effect was greater for words with the syllable break after the third letter.

The results of Experiment 2 show that morphological boundaries are not necessary for the effect of syllables on illusory conjunctions. It is still possible that morphological boundaries may be sufficient. This question is taken up in Experiment 5.

**Experiment 3**

One potential problem with using illusory conjunctions to study units of word perception is that the method, as exemplified in the first two experiments, seems very inefficient. Consider, for example, Experiment 2 in which subjects’ overall error rate was 8.2%. Only about half the errors (58%) were responses of a color of a nontarget item. The remainder were responses of a color that was not part of the stimulus, or they were letter recognition errors (misses or false alarms). If the overall error rate were increased by decreasing the exposure duration, the proportion of letter errors and responses of a color that was not present would also increase, with no guarantee that conjunction errors would increase. To make a conjunction error, subjects must perceive the colors and letters. Several factors may have reduced the number of conjunction errors in Experiments 1 and 2. For example, the target was always the color of three other letters. Subjects could respond correctly by picking the color of most of the letters. In Experiment 3, we used the same words as in Experiment 2, but changed the procedure in an attempt to increase the number of illusory conjunctions.

**Method**

Experiment 3 differed from Experiment 2 in three ways. First, the design was different. In each string of letters, either the first two letters or the last two letters were one color, and the other three letters were another color. The target, as before, was always the middle letter of a five-letter string. Consider the word ANVIL with the letter V as the target. If the first two letters (AN) are pink and the last three (VIL) are blue, then subjects should be unlikely to report the V as pink since pink is not in the same syllable. On the other hand, if the first three letters are pink and the last two blue, subjects should be more likely to report the target as blue, since blue is in the same syllable as the V. The second modification was the use of slightly more discriminable colors. The yellow and pink
matched Munsell values 5Y 8.5/10 and 2.5RP 8/6, respectively. The blue and green were as before. The final modification was the addition of a monetary incentive for subjects to not make letter errors. It occurred to us that some of the letter errors resulted from subjects simply forgetting the target letter. Subjects were therefore rewarded with an additional $.25 for each block that they completed with zero- or one-letter errors. As in the previous experiments, the exposure duration was adjusted between blocks to obtain approximately 10% errors. The mean exposure duration was 13 refresh cycles at 60 Hz (217 ms) and ranged from 8 to 22 cycles. As before, data were collected over six blocks of 80 target-present and 10 target-absent trials. Twelve subjects, recruited as before, participated.

Results and Discussion

Overall, subjects made errors on 12% of the trials, but the vast majority of errors were conjunction errors. Subjects made a mistake on the letter (miss or false alarm) on only 1.3% of the trials, and they responded with a color that was not part of the display also on only 1.3% of the trials. (These percentages included both target-present and target-absent trials.)

The results from the target-present trials are shown in Table 1. This table uses typeface to indicate the color patterns in the stimuli; the nontarget color is indicated with boldface. Considering only the target-present trials, subjects responded with the color of a nontarget letter on 11.3% of the trials. Averaging across the two types of target-present stimuli, 15.6% of the errors were the color of letters in the same syllable, and 6.9% were the color of letters in a different syllable.

The present design, which is vastly more effective at eliciting conjunction errors, seems to reflect the same processes observed previously. As in Experiment 2, the syllable effect was reliable, min $F'(1,28) = 28.4, p < .01$. Again, the effect appeared to be stronger for words with the syllable break after the third letter than after the second letter. The interaction was significant in separate analyses over subjects and stimuli, $F(1,11) = 7.32$ and $F(1,18) = 8.05$, respectively, $p < .05$. It was not reliable simultaneously over both, however, min $F'(1,28) = 3.83, .1 > p > .05$. Nevertheless, we suspect that the interaction is real since the same pattern has appeared in two experiments.

This experiment superficially resembles a lexical decision study by Taft (1979) that varied the case of letters either within or between syllables (TOday vs TODay). One might ask whether Experiment 3 is simply a replication of this previous work. The answer is negative on several grounds. First, the present task does not require lexical access. Second, we found the same syllable effect with pseudowords as well as words (Experiment 1), whereas Taft (1979) did

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* The color pattern is indicated with the typeface. The syllable break is indicated with a vertical line. The target was always the third letter.
not. Finally, the pattern of results in Experiment 3 exactly replicated those in Experiment 2 and color did not mark syllable boundaries in either Experiments 1 or 2.

Experiment 1 demonstrated that conjunction errors were affected by syllable boundaries. Experiments 2 and 3 demonstrated that morphological boundaries are not necessary for a syllable effect. These experiments show that constraints between the co-occurrence of consonants within syllables are sufficient to affect illusory conjunctions. Experiment 4 directly compares phonological and orthographic syllables.

**Experiment 4**

In Experiments 2 and 3, orthographic and phonological factors were confounded. Consider the word VODKA. A sequence of letters like DK does not occur syllable-finally or syllable-initially, and therefore D and K must be assigned to separate syllables on orthographic grounds. Likewise, the sequence of consonant phonemes /dk/ does not occur syllable-initially or syllable-finally and therefore the phonological boundary is also between /d/ and /k/. It is possible to unconfound orthographic and phonological factors by using words like LAPEL and CAMEL. Orthographically, P and M can be either syllable-initial or syllable-final. Therefore, it is not clear where a purely orthographic boundary should be placed. Taft (1979) has suggested that in such cases subjects assign the consonant to the first syllable (cf. Lima & Pollatsek, 1983). This principle predicts the syllabifications LAP/EL and CAM/EL.

While orthographic factors predict parallel syllabification for words like LAPEL and CAMEL, the phonological syllabifications of these words differ. For words like LAPEL that have the second vowel stressed, the consonant belongs to the second syllable (Hoard, 1971; Kahn, 1980; Selkirk, 1982). For words with the first vowel stressed (e.g., CAMEL), the situation is different. According to Hoard (1971) and Selkirk (1982), the /m/ in CAMEL belongs to the final (stressed) syllable; while Kahn (1980) claims that the intervocalic consonant is *amisyllabic* (i.e., belongs to both syllables). In either view, words like LAPEL and words like CAMEL have different phonological syllabifications. Experiment 4 uses these two types of words to ask whether the pattern of conjunction errors reflects phonological syllables. If so, subjects should be more likely to report that the P is the color of the EL than the LA in a word like LAPEL. Words like CAMEL may show the opposite tendency, or they may show no consistent pattern. If the present task reflects only orthographic constraints and not a phonological code, then the two types of words should yield the same pattern of conjunction errors.

**Method**

All the stimuli in this experiment had the form CV/CVC and were monomorphic. Phonologically, twelve of the stimuli had stress on the second syllable and twelve had stress on the first syllable. The former words have CV/CVC syllabification according to the linguistic theories reviewed above and also according to Webster’s Ninth New Collegiate Dictionary (1984). The latter words have CVC/VC structure according to some linguistic theories, but have amisyllabic medial C’s according to others. The syllabification of these words according to Webster’s is CVC/VC, but dictionaries do not indicate that words can be amisyllabic. No words with more than one dictionary syllabification or stress assignment were used. The stimuli are listed in the Appendix. Data were collected in 96 target-present stimuli and 12 target-absent trials in each of six blocks. The mean exposure duration was 13 refresh cycles at 60

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1. In one view (Pulgram, 1970), a CV/CVC word whose second syllable is unstressed has the syllable boundary after the first vowel if that vowel is long (e.g., DE/MON), but not if it is short (e.g., CAM/EL). To avoid this problem, in words with the first syllable stressed, long vowels were not used in Experiment 4.
Hz (217 ms). In all other aspects, this experiment was like Experiment 3.

Results and Discussion

Overall, subjects erred on 10.8% of the trials. Subjects responded with a color that was not part of the display on only 0.23% of the trials, and they made a letter error (miss or false alarm) on 0.68% of the trials. (These percentages are based on both target-present and target-absent trials.) Considering only the target-present trials, subjects responded with the color of a non-target letter on 9.78% of the trials. These errors are shown in Table I.

Although conjunction errors were plentiful, there was no sign that phonological syllables affected the results. The syllable effect did not approach significance either in the analysis over subjects ($F(1,22) = 0.08$, MSE = 9.1136) or in the analysis over words ($F(1,22) = 0.02$, MSE = 38.4508). Furthermore, this factor did not significantly interact with any other factor (all $F$'s $< 1.0$). Considering only words with a phonological syllable break after the second letter (e.g., LAPEL), subjects were not more likely to respond with the color of the last two letters than the first two letters. In fact, there was a trend in the reverse direction (10.1% vs 9.5%), but this difference was not significant ($F$'s over subjects and words were 0.1137 and 0.1268, respectively).

The results provide scant evidence for Taft's (1979) principle of including as many consonants in the first syllable as possible. Although subjects were slightly more likely to respond with the color of the first two letters than the last two letters (10.15% vs 9.4%), this trend did not approach significance in the analysis over subjects ($F = 0.19$, MSE = 85.1515) or in the analysis over words ($F = 0.42$, MSE = 38.4508).

The results of this experiment were in sharp contrast to those of the previous experiments, which found robust syllable effects. Apparently, phonological syllable boundaries are not sufficient to affect conjunction errors. Of course, it might be possible to change our task to induce phonological encoding, but in the present experiment phonological syllabification did not affect performance.

Experiment 5

The final experiment asks whether morphological structure affects conjunction errors. There are two reasons for testing for an effect of morphemes. First, the study by Prinzmetal and Millis-Wright (1984) suggests that morphemes may influence illusory conjunctions. These investigators found that subjects made more conjunction errors with meaningful three-letter abbreviations (e.g., RCA) than nonsense strings (e.g., PNV). Although Experiments 2 and 3 showed that morphological boundaries were not necessary for a syllable effect, morphological structure may still influence illusory conjunctions.

The second reason for testing for an effect of morphemes is to determine whether information stored in the lexicon can influence illusory conjunctions. Since our task does not require lexical access, it might seem unlikely that morphological factors alone would affect performance. If they do not, our failure to find a phonological effect in Experiment 4 is not surprising. Much of the information that determines phonological syllabification in Experiment 4 is stored in the lexicon and is not apparent from the letter string. For example, the letter string BEGIN could be pronounced /'beg in/. There is nothing in the letter string itself to indicate stress assignment. On the other hand, lexical access occurs willynilly in many tasks (e.g., the stroop task). If we do find an effect of morphological structure, this would indicate that lexical information can influence feature integration. The lack of an effect in Experiment 4 would then be specific to phonological information.

Experiment 5 compared five words with a morphological break after the second letter (DEBUG) and five words with a
break after the third letter (PINUP). All the words contained a bound and unbound morpheme or were compound words and all were CVCVC's. Since the medial consonant was always legal in either syllable-initial or syllable-final position, we would not expect an effect based on orthographic factors. The two types of words had different stress patterns, for the most part, but the results of Experiment 4 suggest that this factor alone does not produce a difference in the pattern of conjunction errors.

We also included a nonword condition that was created by replacing the first and last letter of each word with a letter so that the resultant string was very unword-like (e.g., XINUJ for PINUP). The first two experiments showed that conjunction errors were mostly from letters adjacent to the target (middle) letter. It is possible that in the previous experiments the bigram frequencies for letters adjacent to the target and within a syllable were higher than the frequencies for letters adjacent to the target and in a different syllable. If the previous effects were due to different bigram frequencies, the nonwords in this experiment should show the same results as the words.

The 20 stimulus strings are shown in the Appendix. In all other respects, this experiment was identical to Experiments 3 and 4. The mean exposure was 12 refresh cycles at 60 Hz (200 ms) and 12 subjects participated.

Results and Discussion

As in the previous two experiments, subjects were extremely accurate at identifying the target letter. Misses and false alarms totaled only 1.2% of all the trials. Subjects responded with a color that was not part of the stimulus on 0.5% of trials. (These percentages are based on target-present and target-absent trials.) On 12.4% of the target-present trials, subjects responded with a color of nontarget letters. These results are shown in Table 1.

Separate AVOVAs were conducted for words and nonwords. The results for nonwords will be described first. No factors approached significance for the analysis of nonwords either in the analysis over stimulus material or in the analysis over subjects. Table 1 shows that there was a slight tendency to respond with the color of the first and second letter vs the fourth and fifth letter. However, this was true only for 7 of 12 subjects.

For words, there was a significant syllable effect, min $F'(1,13) = 4.9, p < .05$. Eleven out of twelve subjects showed the effect. (With the nonwords, in contrast, only 6 subjects made more errors within a 'syllable'.) Words with a syllable break after the third letter appeared to show a greater syllable effect. However, the interaction between the location of the syllable break and the syllable effect was not significant over either subjects ($F(1,11) = 1.77$, $MSE = 28.2027$) or over words ($F(1,8) = 2.15$, $MSE = 55.90$).

The robust effect for the words in this experiment is in sharp contrast to the results of Experiment 4. In Experiment 4, word structure was defined only phonologically, whereas in the present experiment, word structure reflected morphology. The failure to find a phonological effect in Experiment 4 does not reflect the inability of lexical information to influence illusory conjunctions, since the effect in this experiment does stem from lexical information. Further, since the experiments had about the same number of trials, but only half of the trials in Experiment 5 involved words, Experiment 4 was the more powerful. The difference between the results of Experiments 4 and 5 was shown in an analysis of variance comparing Experiment 4 and performance with the words in Experiment 5. In this analysis, the interaction between experiment and syllable was significant both over subjects ($F(1,22) = 5.04, p < .05$) and over words ($F(1,22) = 5.57, p < .05$). However, the interaction was not reliable with min $F'(1,49) = 2.65$. The fact that it was not reliable by min $F'$ is not too surprising given the conservative
nature of that test and the fact that the interaction is a between-factors test (between different subjects and different words).

It may seem puzzling that stored information about phonology does not influence illusory conjunctions (Experiment 4), while stored information about morphology does have an effect (Experiment 5). If an item in the lexicon is accessed, why is not all the information about that item available? One possibility is that orthographic information is more closely related to morphological information (semantics) than to phonology. Hence, when one sees a word and accesses the lexicon by orthography, morphological information is more likely to be activated than phonological information. Similarly, when one hears a word and accesses the lexicon phonologically, information about what that word means is probably more available than information about how the word is spelled.

**GENERAL DISCUSSION**

Patterns of illusory conjunctions do reflect the perceptual units that are involved in the processing of single words. Our subjects were more likely to incorrectly combine colors and letters within a syllable than between syllables. This pattern of results held for real words and also for pseudowords that resembled words (Experiment 1). However, orthographically illegal nonwords showed no consistent pattern (Experiment 5). Orthotactic constraints on the co-occurrence of consonants within a syllable were sufficient to affect feature integration (Experiments 2 and 3). For example, subjects behaved as if they knew that NV is not a legal syllable-initial or syllable-final cluster, so they divided ANVIL at the N/V boundary. Purely phonological factors did not affect the pattern of errors (Experiment 4). Finally, morphological structure was also reflected in our results (Experiment 5). Thus, our findings show that experienced readers parse written words into syllable-like units on the basis of orthographic and morphological information. Since our task involved only single words, further study would be necessary to determine whether similar patterns of results arise in reading connected text.

With regard to the orthographic information that is used in our task, two issues need to be addressed. First, how should this orthographic knowledge be represented? Second, how do subjects process letter strings to discover these orthographically defined syllables?

One approach to representing orthographic knowledge is to postulate that subjects store the relative frequencies of groups of letters (Miller, Bruner, & Postman, 1954). The results of Experiment 5 show that bigram frequencies do not account for the results since the same bigrams appeared in the words and in the nonwords. Trigram frequency at each position could account for the findings. High frequency trigrams at each position in a five-letter string will generate mostly English words. Alternatively, one could postulate that subjects store a list of all English syllables (Taft, 1979). These approaches have two problems, however. First, they are unparsimonious. A table of position-dependent trigrams for words of different lengths would be needlessly large, as would a list of all English syllables. Second, these approaches are not generative. Since we found similar results with words and word-like pseudowords, orthographic knowledge should be represented in a manner that applies to both words and pseudowords.

Rather than storing lists of trigram frequencies or lists of syllables, subjects might store rules of spelling that generate legal syllables (Haber & Haber, 1983). Subjects know which consonants and consonant clusters are legal at the beginning of a syllable, which vowels and vowel clusters can follow, and finally, which letters and letter clusters can legally end a syllable. This approach is generative and reasonably parsimonious. It can produce many legal syllables that do not occur in English. There are two problems with this type of
representation, however. First, few rules in English orthography are always obeyed. Second, people have intuitions about the sequential frequency of letters and we would not be surprised to find frequency effects with our task.

A reasonable compromise for representing readers' knowledge of orthography is to combine the above approaches. Thus, subjects have a rule that syllables begin with an optional initial consonant element. The representation of these elements would contain information about their relative frequency. The initial element is followed by an obligatory vowel and vowel cluster. Information about which vowel most likely follows which initial consonant could be represented with transitional probabilities. Finally, information about legal final clusters would be represented along with transitional probabilities between the vowel element and the final letter group.

A full account of subjects' use of orthographic information must also consider how syllable boundaries are discovered. For example, when a given consonant can be syllable-initial or syllable-final, to which syllable is it assigned? Consider Taft's (1979) suggestion that subjects include as many letters in the first syllable as orthotactic and morphological factors allow. Our results are weakly consistent with this notion in that each experiment found a small tendency for a larger syllable effect when the first syllable had three letters rather than two. In the last two experiments, where all the stimuli were CVCVC's, 16 of 24 subjects were more likely to respond with the color of the first two letters than the last two letters ($p = .076$). However, the effect was usually very small. If there is a tendency to maximize the initial syllable, it is an optional strategy rather than a rule (cf., Taft, 1979, with Lima & Pollatsek, 1983). Also, the present results do not allow us to rule out the possibility that the tendency to respond with the color of the first two letters reflects greater processing of the left most letters in any string, be it a word or nonword, and is not related to syllables per se (see White, 1969). Further research with the present paradigm may resolve this issue and shed light on the parsing process.

We have considered some of the issues involving the representation and use of orthographic information. The units revealed by our task also reflect morphological information. Experiment 5 demonstrates that these higher-level lexical factors can influence how subjects see the colors in our stimuli. Words like LETUP and DEBUG are equivalent orthographically, but produce different patterns of conjunction errors. How should this "top-down" influence of information stored in the lexicon be conceptualized? One possibility is a system that attempts to match, in parallel, all potential parsings of a string to lexical items. Alternatively, various serial strategies are possible. Further work is needed to specify how lexical information influences performance in our task.

Cognitive psychology has developed several tasks to study word perception. Among these are lexical decision, semantic judgments, naming latency, and letter detection in words. What unique information will the present method offer? An understanding of word perception will probably require more than one approach, each task reflecting a different subset of processes. For example, the lexical decision task reflects the processes of encoding the stimulus, accessing the lexicon, and making a decision. Semantic judgments involve all of these processes plus those that are unique to making a semantic judgment. In the present method, subjects need only form a visual representation of the stimulus. The formation of this representation is presumably part of other more complex tasks. This representation is not phonological (Experiment 4), but it does reflect orthographic constraints. The orthographic constraints are "orthotactic" in nature. They are based on permissible letter sequences within syllables. The visual representation
may also be influenced by morphological information. Compared to other tasks that 
do not require lexical access such as letter search in words (e.g., Spoehr & Smith, 1973), 
the present method seems more sensitive to orthographic structure. It is also 
capable of testing precise hypotheses about this structure and the processes involved 
in word perception.

APPENDIX

Experiment 1: LOWLY, VIRGO, BANJO, 
SIXTY, EARLY, SADLY, ABHOR, AZTEC, 
EXCEL, NYLON, UNZIP, ADMIT, LOXLY, 
VIZGO, BATJO, SINTY, EAML, SAMLY, 
ABNOR, AZREC, EXWEL, NYWON, UNRIP, 
ADHIT.

Experiments 2 and 3: BALSA, BAWDY, 
BUNCO, DOWDY, FANCY, LARVA, SALVO, 
SIGMA, SULFA, VODKA, ALBUM, ANVIL, 
ARBOR, INFER, ARGOT, ARMOR, ATLAS, 
AWFUL, ENROL, INLET.

Experiment 4: CAMEL, SALAD, GIVEN, 
PIVOT, VIGOR, FACET, RAPID, LEVEL, 
RELIC, SONIC, VISIT, LEMON, LAPEL, 
BEGIN, CANAL, CADET, DEFER, KAPUT, 
RECUR, SEDAN, REMIT, RELAX, DEMUR, 
BESET.

Experiment 5: LETUP, SETUP, GETUP, 
PUNUP, SUNUP, TODAY, BYLAW, BEFIT, 
DEBUG, REPAY, XETUH, QETUK, XETUJ, 
XINUH, XUNUJ, XODAQ, QYLAIJ, XEFIJ, 
XEBUQ, QEPAJ.

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